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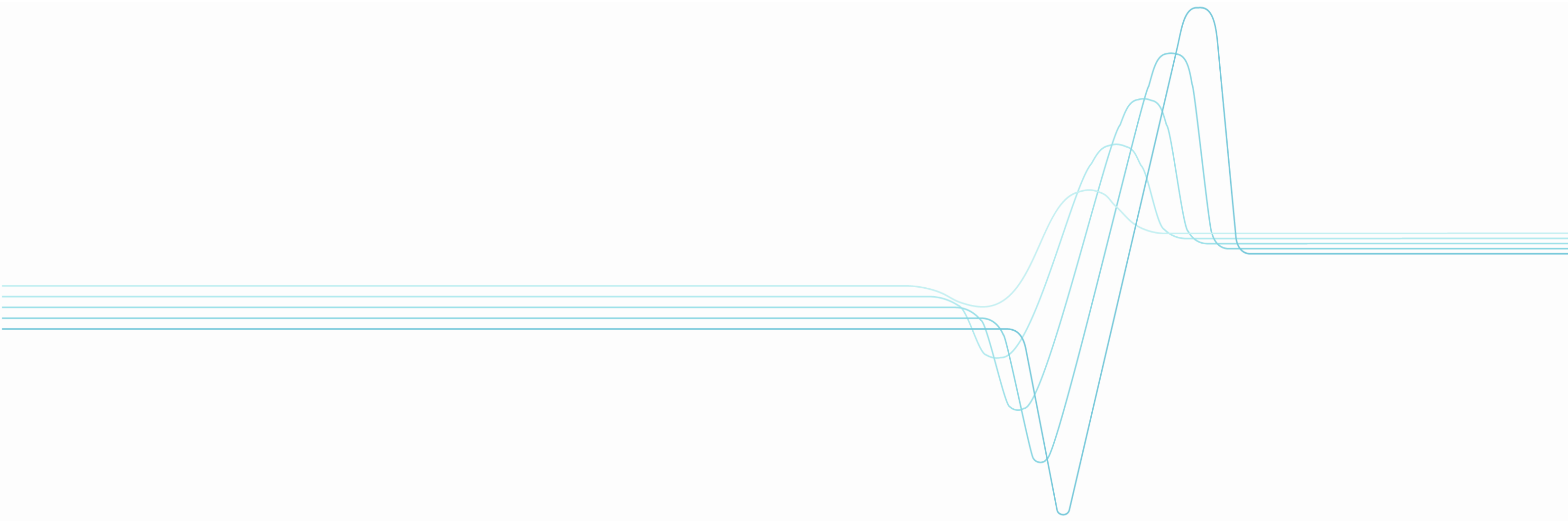

Moisture performance properties of exterior sheathing products made of spruce plywood or OSB

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Moisture performance properties of exterior sheathing products made of spruce plywood or OSB

Abstract

Plywood and OSB (Oriented Strand Board) are building boards that are made of timber and glue and that have good structural strength. OSB is a relatively new product that is produced from various timber materials and even some wastewood can be used as raw material for this product. Due to the easy access of raw material and economical reasons, the use of OSB has been highly increasing. The moisture safety of the building envelope depends on the properties of the building products. The moisture performance properties of the sheathing boards have not got enough attention, too often these wood based materials are equated without considering the real properties and their effect on the overall moisture performance.

This research was carried out to experimentally determine the material properties and performance characteristics that have an effect on the moisture performance of building structures where OSB or spruce plywood are applied as exterior sheathing boards. A relatively representative amount of samples were used to study the moisture properties of European OSB and plywood products and a comparison to one Canadian OSB and one plywood product was done. All the products used in this research were meant to be used also as exterior sheathing boards.

The results shows clearly the differences between OSB and plywood products. The products are not interchangeable. The main differences can be found from the vapour permeability levels that have an effect on the drying efficiency of building structures. The products have different performance criteria, and the climate conditions and moisture loads have to be studied to evaluate their suitability and moisture safety aspects in different applications. Water repellent features and drying efficiency are somewhat opposite properties of the products and the dimensional changes under varying moisture contents can set some boundary conditions when the optimum solution for the exterior sheathing is considered.

Keywords
building envelope, material properties, moisture content, drying efficiency

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Preface

This report presents the results from the research project "Rakenteiden tuulensuojauksen toimivuus ja toteutus havuvanerin ja OSB:n avulla – Vaihe I: Materiaaliominaisuudet ja kuivumiskyky" (Performance and implementation of the exterior sheathing made of spruce plywood or OSB – Phase I: Material properties and drying efficiency), which has been funded by Wood Focus Oy, TEKES (the National Technology Agency of Finland) and VTT. The steering group was Keijo Kolu, chairman (UPM-Kymmene Wood Oy), Markku Mäkelä and Juha Vaajoensuu (Tekes), Aarni Metsä (Wood Focus), Jouko Veistinen (Finnforest Oyj) and Laura Apilo (VTT).

This research was carried out at VTT Building and Transport. Senior research scientist Tuomo Ojanen was the responsible researcher of the project. The experiments were carried out by research engineer Hannu Hyttinen and his team. Senior research scientist Leena Paajanen analyzed the timber materials and research engineer Mia Löija the glues of the specimens. Trainee research scientist Jarkko Ahonen took part in the final analysis of the experiments and the reporting of the results.

The contributions of the members of the steering group and working group are appreciated.

Espoo, January 2005,

Project team

Contents

Appendix A

List of symbols

d	thickness	m
ℓ	air permeability	$m^3/m \cdot s \cdot Pa$
ℓ_k	air permeability factor	$m^3/m^2 \cdot s \cdot Pa$
RH	relative humidity	%
RH_{ave}	average relative humidity	%
Z_p	water vapour resistance	m^2sPa/kg
S_d	water vapour diffusion equivalent	
	air layer thickness	mm
ρ	density	kg/m^3
δ_p	water vapour permeability	kg /msPa
μ	water vapour resistance factor	-

1. Background and objectives

The building envelope systems are often done by experience and opinions of practitioners rather than well-established methodology. Different structural solutions or products are not safe to apply in different climate or indoor air conditions without thorough analysis of their performance properties. A lot of failures of the moisture performance of the building envelope have been studied. These failures can involve the loss of the structural integrity of the envelope, increased heat losses, thermal bridges, air leakage flows and convection caused heat and moisture transport in through the structure or just increased risks for moisture accumulation that may be revealed only in conjunction of some other accidental load. Typical first consequences are the growth of moulds in the envelope that can even contaminate the indoor air space.

OSB (Oriented Strand Board) and plywood are typical sheathing boards that are meant to be used also as exterior sheathings. Compared to plywood, OSB is a relatively new product that is produced from various timber materials. OSB has typically wax at least on the surface layers in order to protect the board against water absorption during the building process. Depending on the purpose of use, plywood can be produced from different timber materials. Softwood, typically spruce, is applied in the products meant to be used as exterior sheathing.

These products are composites of timber, glue and possible wax and there are similarities also in the production process. The moisture performance of building structures depend on the moisture characteristic properties of the material layers used in the structures. The existing information about OSB and plywood shows that the moisture performance properties are not equal for the products (Ojanen 1993, Ojanen et al. 1997). It is important to know these properties that have a significant effect on the moisture performance and moisture safety of the building envelope. This research was carried out to determine the main moisture performance characteristics of the products so that they could be safely applied in different climate and indoor load conditions. Especially in cold and mild climates the vapour permeability of the exterior sheathing board represents the drying efficiency of the structure. Higher drying efficiency gives more safety against moisture loads that are accidental or exceed those used as design parameters.

The objective of this research was to study experimentally the moisture performance properties of OSB and plywood products in order to be able to set the performance characteristics for the structures where these products are applied and to use this data in numerical simulation models. This makes it possible to study the moisture safe structural solutions to be used under different conditions.

2. Contents of the research

This stage of the research covered the experimental determination of the moisture physical and performance properties of typical selected OSB and spruce plywood products that are meant mainly to be used as exterior covering boards of the thermal insulation cavity of a wood frame structure.

2.1 Products used in the experiments

Nine products were included in the research: five OSB- and four plywood products, one OSB and plywood were Canadian products and the others were European (Figure 1). The products were well specified by names and types, but in this report only product codes are presented so that OSB and plywood and the European and Canadian products can be identified. Table 1 presents the used code, measured board thickness and dry density of each product.

Table 1. Products used in the experiments. Thickness and dry density values are the average of six samples.

Product code	**Thickness** d [mm]	**Dry density** ρ [kg/m^3]
Plywood EU (3 PLY)	9.0	424.4
Plywood EU (5 PLY)	12.2	434.2
Plywood EU 2 (3 PLY)	8.5	451.1
OSB	8.4	602.9
OSB EU	12.6	573.2
OSB EU 2	12.3	590.1
OSB EU	15.5	586.2
Plywood CAN (4 PLY)	12.8	394.9
OSB CAN	11.6	579.3

Figure 1. Samples of products used in the experiments. OSB (lower left) and plywood (lower right).

The products used in this research were mostly known by their product names and origin, but the product parameters were not specified in detail for all of the products. There was a need to determine the main components of the products, at least the timber material, the glue and possible also the wax types used in the products. In the following the determination of some of the product components will be presented.

2.2 Determination of timber and glue materials of the products

The product samples were analysed using stereo- and transmission microscopes and by analysing the samples by using FTIR-method (Fourier Transform Infra-Red spectroscopy). The spectrums of the product surfaces were scanned by using surface-sensitive ATR-IR method (Attenuated Total Reflection) and also by applying microscopic transmission method.

2.2.1 Identification of the timber materials

The analysis of the timber materials of the products included some difficulties. The analysis is based on transmission microscopic inspection of the cut wooden samples. Separation of suitable samples for inspection from the glued compound was difficult especially from the wood chips inside the boards. The samples had to be cut against the grains to be able to analyse the pore structure of the material. The wood chips were thin and thus the dimensions of the cut surface were relatively small compared to the needed sample size. Therefore the results presented in Table 2 may contain some uncertainty.

Table 2. Timber raw materials analysed from test samples.

Product	**Microscopic analysis results**
Plywood EU (3 PLY) 9 mm	Spruce
Plywood EU 2 (3 PLY) 9 mm	Spruce
OSB (EU) 8 mm	Softwoods, (unknown) hardwood too
OSB EU 12 mm	Principally pine (*Pinus*, possibly *Pinus sylvestris*), and in addition also spruce (*Picea*)
OSB EU 2–12 mm	All the examined samples were pine (*Pinus)*
OSB EU 15 mm	Softwoods, spruce (*Picea)* and some pine (*Pinus)*
OSB EU 2–15 mm (not included in the research)	Surface layer is pine (*Pinus)* Centre layer contains also Douglas fir (*Pseudotsuga menziesii*)
Plywood CAN (4 PLY) 12 mm	Surface plies are spruce (*Picea)* One inside ply is poplar (*Populus),* Other inside plies are spruce as the surface plies
OSB CAN 11 mm	Softwoods, principally poplar (*Populus,* possibly *deltoides),* also some birch (*Betula*)

2.2.2 Identification of the glues by microscopic and FTIR-methods

The product samples were analysed from surfaces and the cut edges. Glue particles were separated from the samples by microscopic preparation.

All the samples had small amounts of phenolic-resin glue. This could be detected by the dark colour of the glue and also by chemical analysis. The detection, preparation and determination of other more transparent glue components was not as simple. The analysed phenolic-resin glue may include other components, like melamine-formaldehyde resin (MUF). The exact determination of the amounts of different components would require thorough quantitative research.

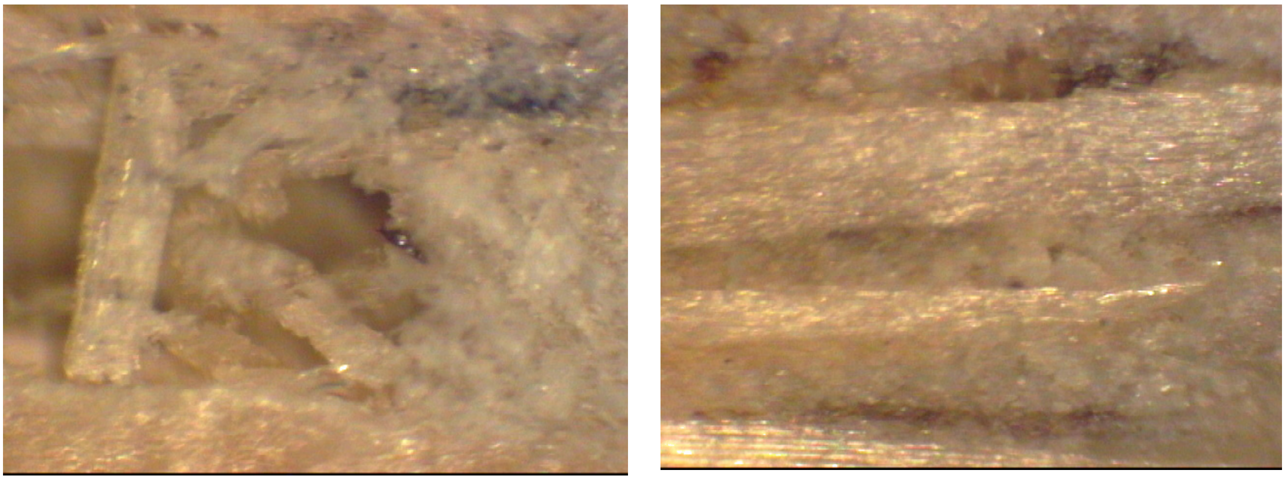
All the OSB products had glue and wax components on the surfaces. These component consists of aromatic and carbonyl compounds, but these components were not specified in detail. The IR -analysis showed that there were same stratified components also inside the OSB-boards.

Table 3. Glues analysed from test samples.

Product	**Density kg/m^3**	**Microscopic analysis**	**FTIR-analysis**
Plywood EU (3 PLY) 9 mm	424	Phenolic-resin	Phenolic-resin
Plywood EU 2 (3 PLY) 9 mm	451	Phenolic-resin	Phenolic-resin
OSB (EU) 8 mm	603	Small amounts of phenolic-resin + wax	Phenolic-resin + wax inside same as surface wax
OSB EU 12 mm	573	small amounts of phenolic-resin	Phenolic-resin + inside wax different than surface wax
OSB EU 2 12 mm	590	Phenolic-resin + wax	Phenolic-resin + wax inside same as surface wax
OSB EU 15 mm	586	Small amounts of phenolic-resin + wax	Phenolic-resin + wax inside same as surface wax
OSB EU 2–15mm *(not included in the research)*		Small amounts of phenolic-resin	Phenolic-resin
Plywood CAN (4 PLY) 12 mm	395	Phenolic-resin	Phenolic-resin
OSB CAN 11 mm	579	Only phenolic-resin	Phenolic-resin

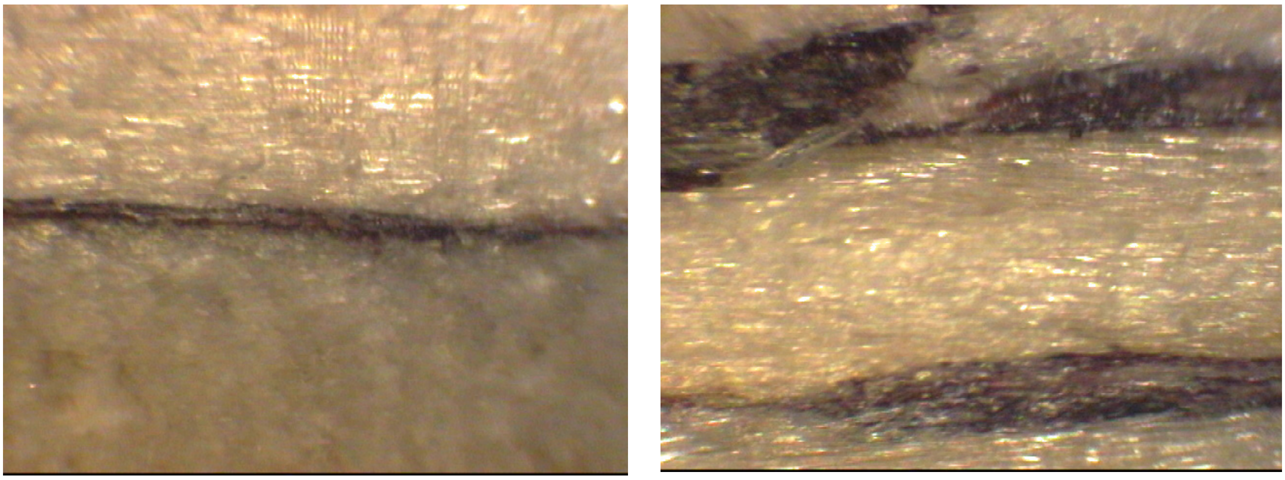
The accuracy of the analysis methods, lack of the reference IR spectrums of all the possible glue components and the amount of samples per product set some limitations to the results. The summary results presented in Table 3 give only the main glue component of the products. The possible wax is not specified, but the inside and surface layers are compared with each other. Small amounts and also different mixtures including other components are quite possible to exist in the products.

Figure 2 presents pictures taken from some samples using the stereo microscope. These represent typical surface formation of the product samples. The dark or reddish parts are phenol harts. The European plywood sample had very precise and thin glue layer between plies while the Canadian plywood had significantly more glue, but still some plies were not perfectly connected.



OSB EU 15 mm

OSB EU 2- 15 mm



Plywood EU (3 PLY) 9 mm

Plywood CAN (4 PLY) 12 mm

Figure 2. Microscopic images from the cut surfaces of test samples of four products (40 times magnification).

Figure 3 presents as example two measured IR spectrums and the reference spectrum of phenol glue.

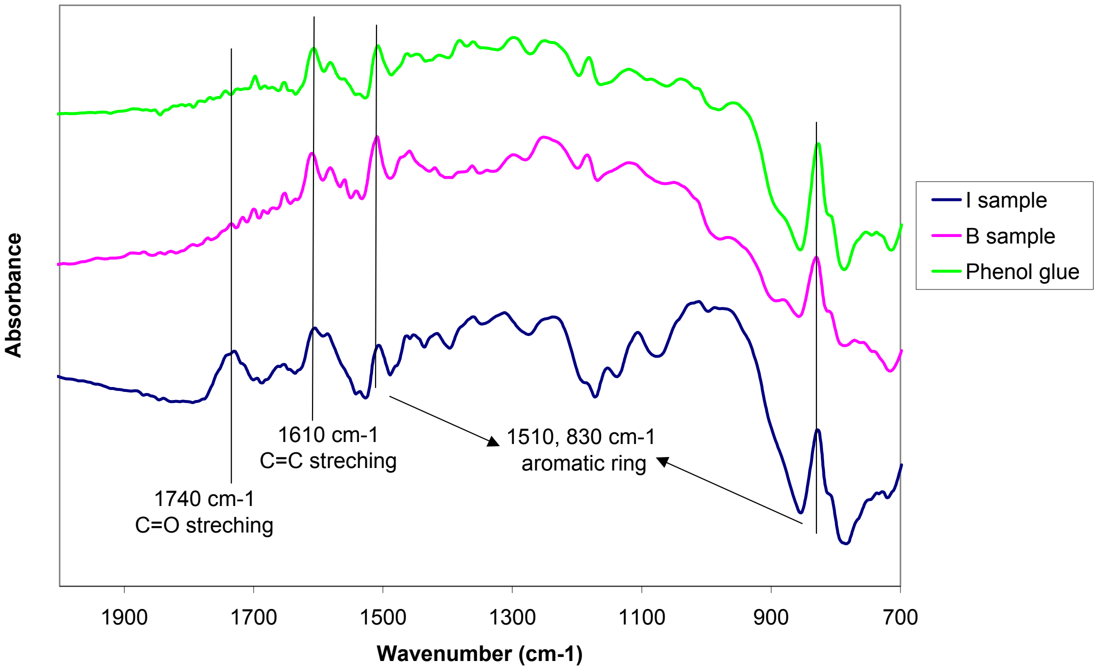


Figure 3. Measured IR-spectrums of two products and the reference spectrum of phenolic-resin. Some parts of the spectrum are pointed out to show the 'finger marks' of the phenol glue. Sample B is Plywood EU 2 (3 PLY) 9 mm and sample I is OSB CAN 11 mm.

3. Experiments and results

The material property determinations were carried out using (CEN -ISO) standardised test methods when available. The applied standards will be briefly described in individual sections of this chapter.

3.1 Air permeability

3.1.1 Test method

Determination of air permeability was based on EN 29053:1993. Air flow through the specimens measured with two or three different pressure differences relied on specimen's tightness. At the test, pressure differences range between 0 and 2000 Pa. Some of the products had so small air permeability, that air flow through the specimen could not be measured even at 2000 Pa pressure difference.

Temperature during the test was 20.0 °C and air pressure 770 mm Hq.

3.1.2 Specimens

Three test specimens size 400 mm x 400 mm was taken randomly from each product sample. Before testing, the test specimens were stored at laboratory conditions, at about +22 °C ± 1 °C temperature and 25 % ± 5 % RH humidity conditions.

3.1.3 Test results

Air permeability

Test results are shown in Table 4.

Table 4. Measured air permeability values.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN ℓ [m^3/m·s·Pa x 10^{-9}]**	**MAX ℓ [m^3/m·s·Pa x 10^{-9}]**	**MEAN ℓ [m^3/m·s·Pa x 10^{-9}]**
Plywood EU	9.0	424.4	*	*	*
Plywood EU	12.2	434.2	*	*	*
Plywood EU 2	8.5	451.1	0.0184	0.048	0.035
OSB	8.4	602.9	17.3	27.9	24.1
OSB EU	12.6	573.2	6.55	18.5	10.8
OSB EU 2	12.3	590.1	4.65	7.10	6.26
OSB EU	15.5	586.2	25.6	36.4	30.8
Plywood CAN	12.8	394.9	*	*	*
OSB CAN	11.6	579.3	2.00	2.24	2.13

**The air permeability of the product was so low that the air flow rate trough the specimen could not be measured.*

Air permeability factor

Air permeability factors are shown in Table 5.

Table 5. Air permeability factors.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN ℓ_k [m^3/m^2·s·Pa x 10^{-9}]**	**MAX ℓ_k [m^3/m^2·s·Pa x 10^{-9}]**	**MEAN ℓ_k [m^3/m^2·s·Pa x 10^{-9}]**
Plywood EU	9.0	424.4	*	*	*
Plywood EU	12.2	434.2	*	*	*
Plywood EU 2	8.5	451.1	2.10	5.70	4.03
OSB	8.4	602.9	2090	3360	2910
OSB EU	12.6	573.2	533	1480	870
OSB EU 2	12.3	590.1	384	582	516
OSB EU	15.5	586.2	1650	2330	1990
Plywood CAN	12.8	394.9	*	*	*
OSB CAN	11.6	579.3	172	202	186

**The air permeability of the product was so low that the air flow rate trough the specimen could not be measured.*

Conclusion

The building codes can set requirements or recommendations for the maximum value of the air permeability factor of the wind barrier product. In Finland the recommended maximum value is 10^{-5} m^3/(m^2· s · Pa). All the tested products have very small air permeability factor and they are all quite suitable for the use as a wind barrier in conventional wall structures. The maximum measured value was about 1/3 of the recommended maximum level in Finland.

A significant scattering of the air permeability was found between the products and also between the samples of some products. In addition to the thickness of the specimen also the production method and board structure, size of wood chips used in the products and the glue may have caused the variety in the test results.

3.2 Water vapour permeability under four different RH conditions

The objective was to determine comprehensive water vapour permeability curve as a function of the humidity conditions of the materials. This is needed both for evaluating the vapour permeability of different products under varying moisture content and humidity conditions and for the numerical simulation of the hygrothermal performance of the products in structures. In addition to the standard dry- and wet- cup conditions two additional humidity conditions were applied according to the standard measuring procedure.

3.2.1 Test method

Water vapour transmission properties determined by a cup method based on EN 12086 (1997), Set B: Thermal insulation products for building materials - Determination of water vapour transmission properties. The standard recommends two different condition, wet cup and dry cup to determine water vapour transmission properties. In this study we added two different conditions to get more complete and reliable test results. Also we used so called "blind cup" to make sure that the mass flow through the specimen has reached steady state.

In the cup method specimen is sealed to the open side of a test cup containing either desiccant or an aqueous saturated solution and the test cup is placed to the temperature and humidity controlled test chamber. The difference in partial vapour pressures between the chamber and the cup causes vapour flow through permeable specimen. By weighing the cup periodically the rate of vapour flow through the specimen can be calculated. When the vapour flow is constant (steady state) we can calculate water vapour transmission properties for the tested material under the specific test condition (relative humidity and temperature).

3.2.2 Test conditions

All nine materials were tested in four different humidity conditions at constant temperature T = 22 °C (Table 6). The conditions used in set A represent the dry cup test and those in set C the wet cup test according to the standard. Four relative humidity ranges give enough information to define the vapour permeability of the material under different relative humidity conditions. Set D represents very humid conditions and the set B was chosen to represent high, but still safe level of humidity. Relative humidity level 80 % RH is considered to be the pivot value for the starting risks of fungal growth. When the temperature is lower than 15 ºC, also this critical level of relative humidity starts to increase (Viitanen et al. 2003). Typically the temperature of the exterior sheathing is close to outdoor air temperature, and thus the relative humidity level used in test condition set B can be considered safe in cold climate conditions.

Table 6. Conditions used in the water vapour permeability tests.

Set	Temperature	RH (1)	RH (2)	RH_{aver}
A	22 °C	0	50	25
B	22 °C	58	80	69
C	22 °C	48	94	71
D	22 °C	72	94	83

3.2.3 Specimens

Circular specimens were cut from the nine products randomly, six specimens per each test set. Diameter of the specimens was 160 mm. Before the test, the specimens were at indoor temperature conditions (+23 °C) for at least six hours.

In each test set we used five specimens per each material sample. One of the six specimen was used as a "blind cup". The use of blind cup allows to observe when the material has reached the test chamber conditions. Blind cup is one way to improve the reliability of the test results. In chapter 3.2.6 the use of blind cup to reduce errors in the test results will be discussed in a more detailed way.

3.2.4 Test results

Results from all test sets are shown in Appendix A. In every test set we defined water vapour permeability, water vapour resistance, water vapour resistance factor and water vapour diffusion equivalent air layer thickness. In Appendix A some of the results are also shown in US units.

Water vapour permeability

Figure 4 represents the water vapour permeability as a function of the average relative humidity of the test conditions for all the products.

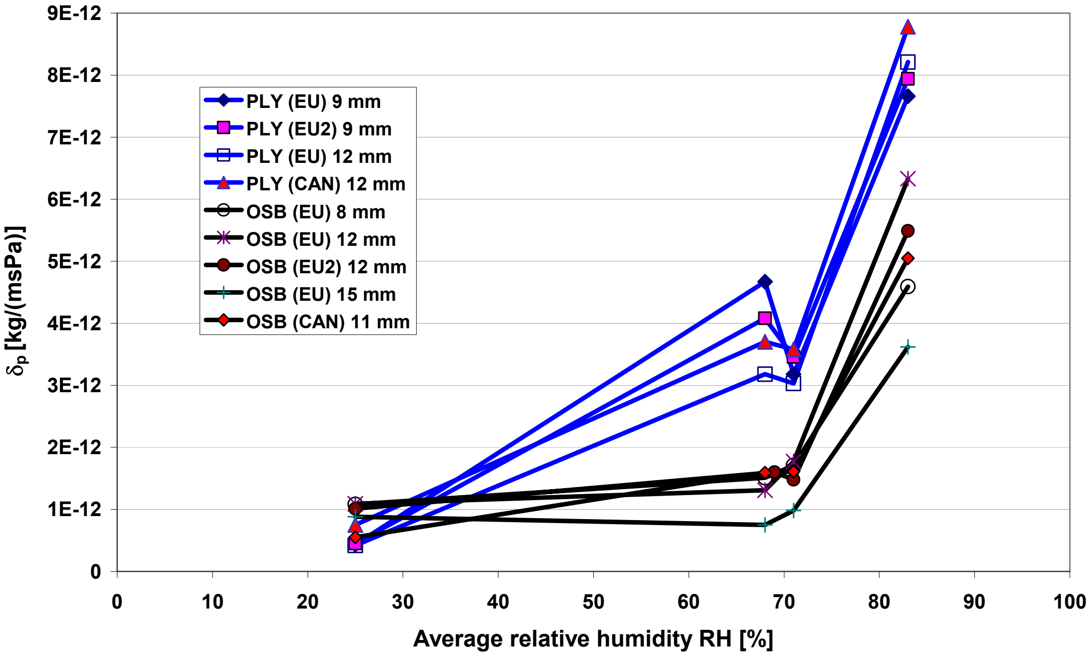


Figure 4. Water vapour permeability as a function of the average relative humidity of each test set.

Conclusion

The water vapour permeability of a material typically increases with higher relative humidity. That influence is also seen in Figure 4. However, the relation on relative humidity is different between OSB and plywood. At average relative humidity less than 30 % OSB has higher water vapour permeability than plywood whereas at higher RH levels plywood has higher values.

Under wet cup and lower humidity conditions (test sets B and C) OSB had about the same vapour permeability level as under dry cup conditions, whereas the vapour permeability of plywood was, depending on the product, increased to be about 2 - 5, (and even 6) times higher than that of the OSB.

Figure 4 shows that the test set C gives almost the same or even smaller water vapour permeability values than the test set B. The reason for smaller values may be due to the different moisture distribution within the specimen. Because moisture distribution within the specimen is not linear, the average relative humidity is not the average of the boundary conditions.

Test set B (80 % / 58 % RH) represents to high, but still safe moisture conditions. The vapour permeability determined under that humidity range was about the same as that derived from wet cup tests (test set C). Thus the value from wet cup test gives a good approximation for the level of vapour permeability under moisture safe conditions. The wet cup test values can be used to represent moisture safe level for the exterior sheathing board in typical applications and conditions in cold and moderate climates.

Water vapour resistance

Water vapour resistance can be calculated from water vapour permeability, when thickness of the specimen is known. Water vapour resistance is calculated from equation 1

$$Z_p = \frac{d}{\delta_p} \qquad (1)$$

where

d is thickness of the specimen and

δ_p is water vapour permeability

Figure 5 shows the average water vapour resistance for all the products (average of five test specimens under each condition) at different average relative humidity conditions.

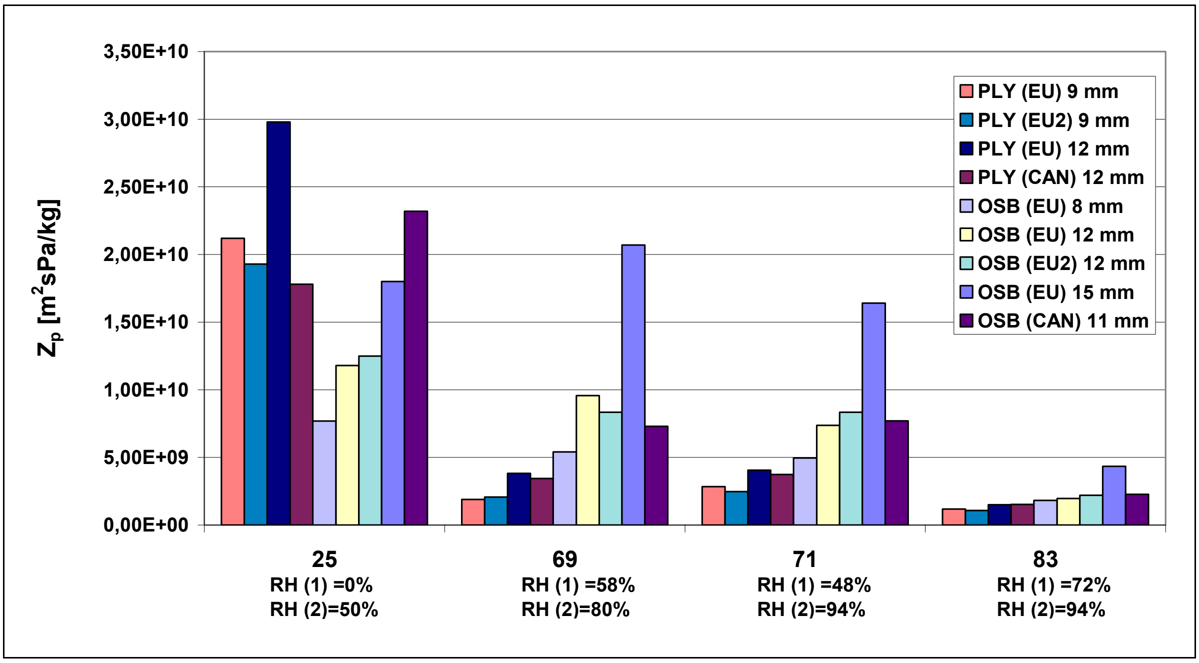


Figure 5. Water vapour resistance values as a function of average relative humidity.

Conclusion

Some of the North European countries have set in their building codes maximum values for water vapour resistances, when building material are used as a wind barrier. For example, in Sweden the maximum value is $2.7 \cdot 10^{+9}$ m^2sPa/kg and in the Norway $9.6 \cdot 10^{+9}$ m^2sPa/kg. Figure 6 shows that only two of the products had water vapour resistance value less than the Swedish requirement under 'mould safe' 80/58 % RH conditions.

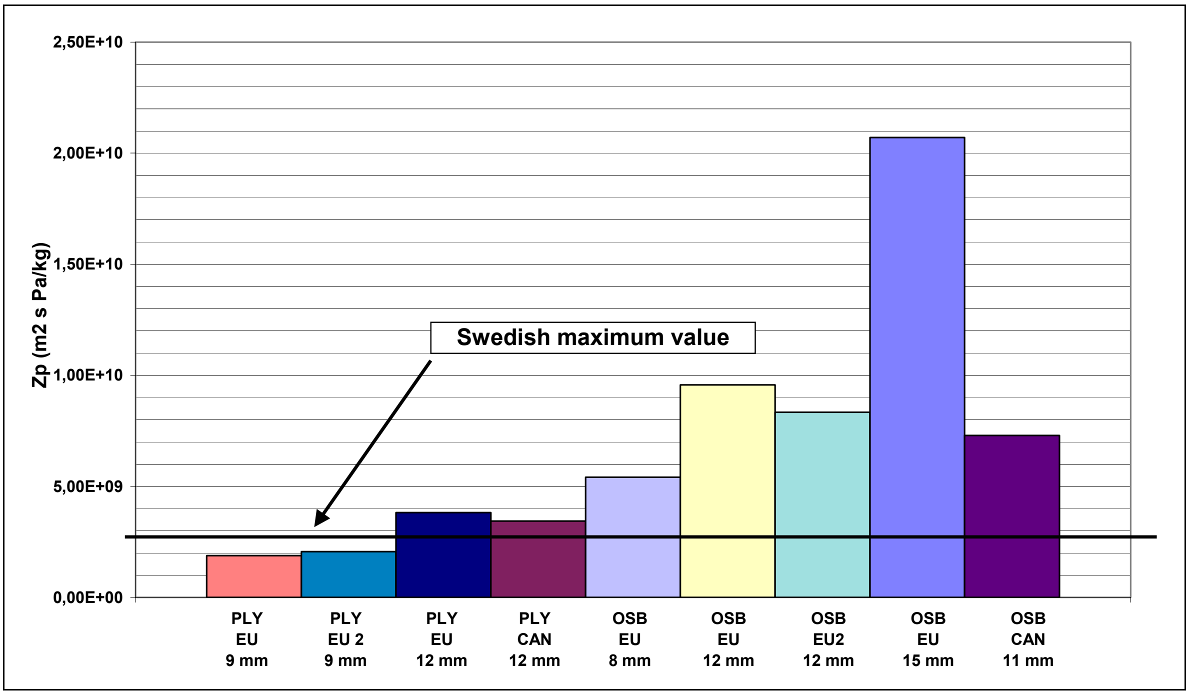


Figure 6. Water vapour resistance values for OSB and plywood products under80/58 % RH conditions. Level $2.7 \cdot 10^{+9}$ m^2sPa/kg represents the requirement in Swedish building code.

Water vapour diffusion equivalent air layer thickness

Water vapour diffusion layer thickness S_d is the value that can also be used to describe water vapour permeability of the material. S_d shows the thickness of air through which the amount of vapour diffusion is the same as the moisture flow by diffusion through the specimen. Materials with larger S_d values are not as permeable as materials with smaller S_d values. The S_d values for OSB were in the range of 0.36 m to 4.53 m and that of plywood between 0.21 m and 5.76 m, depending on the relative humidity. All the results are presented in Appendix A.

Water vapour resistance factor

The water vapour resistance factor μ is also used when comparing water vapour transmission properties of different materials. The water vapour resistance factor can be calculated as a division of S_d and the average thickness of the specimen. The μ-values for OSB were in the range of 30.9 to 396.3 and those for plywood 22.3 to 470.1. All the results are presented in Appendix A.

3.2.5 Water vapour permeability and the units

Water vapour permeability can be expressed in different units. In Europe the SI unit system is used and the unit for the water vapour permeability is δ_p [kg/m·s·Pa]. Water vapour permeability in the US unit system is expressed in Perm-inches, where perm is [grains per square foot per hour per inch of mercury difference in vapour pressure]. It is important to know in which unit system the results are given and under which conditions they are determined. Table 7 gives conversion the factors to make it easier to convert different permeability values from the US unit system to the SI unit system and vice versa.

Table 7. Conversion factors for different units.

To convert from	to	Multiply by
1 Perm · inch (0 °C)	kg/m·s·Pa	1.45322×10^{-12}
1 Perm · inch (23 °C)	kg/m·s·Pa	1.45929×10^{-12}
kg/m·s·Pa	1 Perm · inch (0 °C)	$6.88127 \times 10^{+11}$
kg/m·s·Pa	1 Perm · inch (23 °C)	$6.85265 \times 10^{+11}$
1 Perm (0 °C)	$kg/m^2·s·Pa$	5.72135×10^{-11}
1 Perm (23 °C)	$kg/m^2·s·Pa$	5.74525×10^{-11}
$kg/m^2·s·Pa$	1 Perm (0 °C)	$1.74784 \times 10^{+10}$
$kg/m^2·s·Pa$	1 Perm (23 °C)	$1.74057 \times 10^{+10}$

3.2.6 Blind cup

The blind cup was used in the experiments to make sure that the water vapour flow through the specimen had reached steady state. Here is presented one example about the influence of the blind cup on the test procedure. Figure 7 represents the weighing profiles of the five test samples of OSB EU 15 mm product and the blind cup during the first 55 days under 80 / 58 % RH test conditions.

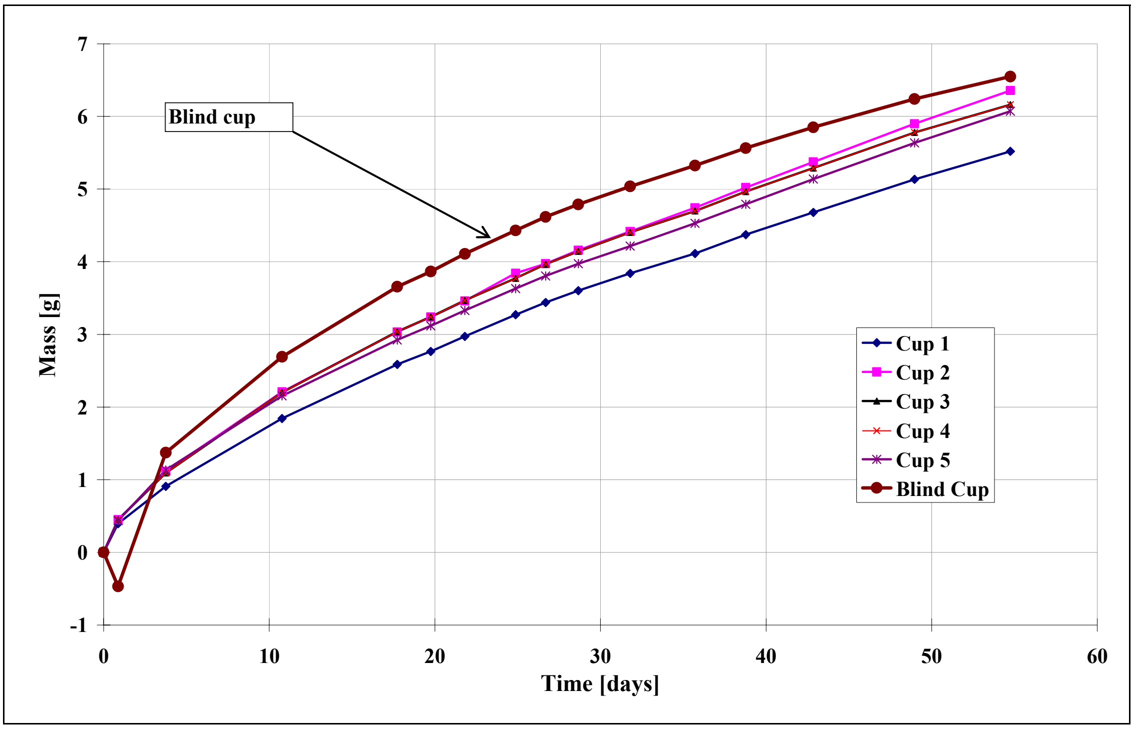


Figure 7. Weighting profiles for the OSB EU 15 mm and a blind cup.

At the end of the presented under review, the mass change of the blind cup was still about in the same level as that measured for the actual test samples. When the steady state conditions are reached, the blind cup should have constant mass.

With more vapour open material the steady-state conditions for the blind cup will typically be reached in a few days. In that case it would be better to use the additional test sample to actual measurements instead of using it as a blind cup. With plywood samples the steady state conditions were reached in good time before the end of the test periods and no blind cup correction was needed.

However, if the presented weighing results for the OSB test specimen were considered to have reached steady-state conditions (due to low change of the slope, long measuring time, ect.) the water vapour permeability values solved from this data would include drastic errors.

The need for the blind cup is caused, not only by the low vapour permeability, but also by the sorption properties of the tested material. Though the vapour flow into the material is measurable, it takes a long time before this causes steady-state moisture flow between the inside surface of the sample and the inside air of the cup. In the presented case the steady-state was not reached even in 55 days. Without the blind cup, it is obvious that the tests may easily result in false interpretation of the time when steady-state is reached. Thus the determined water vapour permeability results may include severe error, if special care is not taken to ensure that steady state conditions have been reached. A blind cup is a simple instrument to ensure this.

3.2.7 Comparison between test results and SFS-EN 13986

Standard SFS-EN 13986: Wood-based panels for use in construction - Characteristics, evaluation of conformity and marking, presents values for water vapour resistance of OSB and plywood. These values can be used if the vapour resistance values have not been determined for the product under consideration. Table 8 presents the comparison of water vapour resistance values determined for one representative OSB (OSB EU 12 mm) and plywood (Ply EU 9 mm) exterior sheathing products with those presented in SFS-EN 13986. Test results in wet conditions means results derived from wet cup tests and dry conditions results from dry cup tests. SFS-EN 13986 values are for plywood (400 kg/m^3) and for OSB (650 kg/m^3).

Table 8. Comparison of water vapour resistance values at this research and SFS-EN 13986.

Material	**Test results**		**SFS-EN 13986**	
	μ [-] (Wet)	**μ [-] (Dry)**	**μ [-] (Wet)**	**μ [-] (Dry)**
Plywood	**62**	457	**60**	175
OSB	**116**	185	**30**	50

Under wet conditions the measured μ-values for plywood were almost the same as in the reference standard, but under dry conditions the measured values were about 2.6 times higher. The measured μ-values for OSB were both under wet and dry conditions 3.7–3.9 times higher than those presented in the standard. Higher μ-value means higher vapour resistance.

In the cold and moderate climates the drying of structures takes place mainly by moisture transport through the exterior surface towards the outdoor air, while the interior sheathing has typically the role of air- and vapour barrier. Under such climate conditions the exterior sheathing is most time of the year in conditions that correspond closely to those used in the wet cup tests. The dry cup conditions correspond closely to the interior sheathing conditions under heating period. The drying efficiency of a structure depends strongly on the vapour permeability of the exterior sheathing board under critical wet conditions. When a standard presents inaccurate vapour permeability values for a product that is used as exterior sheathing, it may result in structure designs that have enhanced risks for moisture accumulation and damages caused by the excess of moisture. Correction of the property values is needed to be able to design moisture safe structures with materials suitable for each climate and moisture load conditions.

3.2.8 Comparison of test result to the literature

In the literature water vapour permeability of studied materials are shown quite well as a function of relative humidity. Because wind barriers are usually in wet conditions we concentrate in this comparison only for wet cup values.

Table 9 shows the scattering of the test results for OSB and plywood products compared to some values from literature. (Kumaran 1996, Mukhopadhyaya et al. 2003). The measured values are in same order as those presented in the literature.

Table 9. Comparison of water vapour permeability at this research and literature.

Material	**Literature** δ_p **[kg/(msPa)]**	**Test Results** δ_p **[kg/(msPa)]**
Plywood	$4.48 \cdot 10^{-12}$	$3.7 \cdot 10^{-12}$ - $4.7 \cdot 10^{-12}$
OSB	$1.5 \cdot 10^{-12}$	$0.75 \cdot 10^{-12}$ - $1.6 \cdot 10^{-12}$

3.3 Sorption properties

Sorption properties as adsorption and desorption curves were determined based on standard EN ISO 12571(1999): "Determination of hygroscopic sorption properties".

3.3.1 Test method

Three equal (30 mm x 100 mm) test samples were taken randomly from the nine products. Before the tests the specimens were dried at 70 °C temperature. The specimens were placed in test chambers having set relative humidity conditions. Test specimens were weighted periodically at four different relative humidity levels. Temperature during the test was about constant, +23 °C. When the mass of the specimen had reached constant level, the water content of the specimen could be solved as the ration of the wet and dry mass. The relative humidity values used in the adsorption test were 33.0 %, 58.5 %, 75.0 % and 97.7 %. The desorption test started from 97.7 % RH and the same RH levels were used as in the adsorption test.

3.3.2 Test results

Test results for adsorption and desorption are shown in Figure 8 and Figure 9.

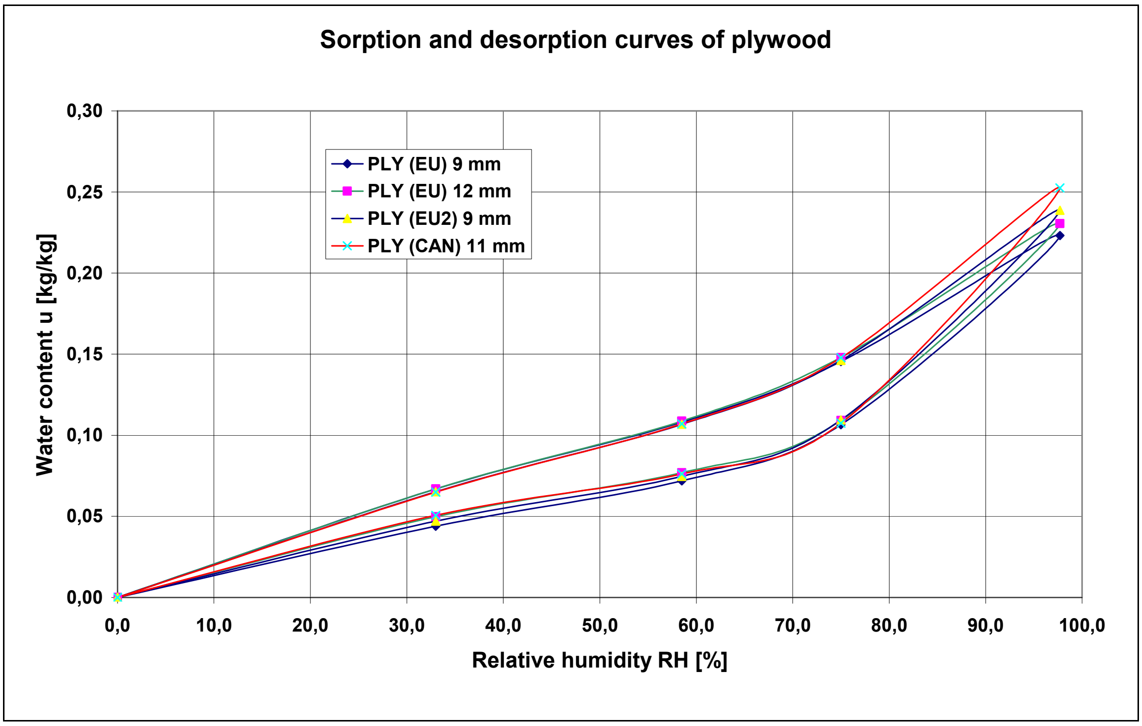


Figure 8. Sorption and desorption curves of the plywood products.

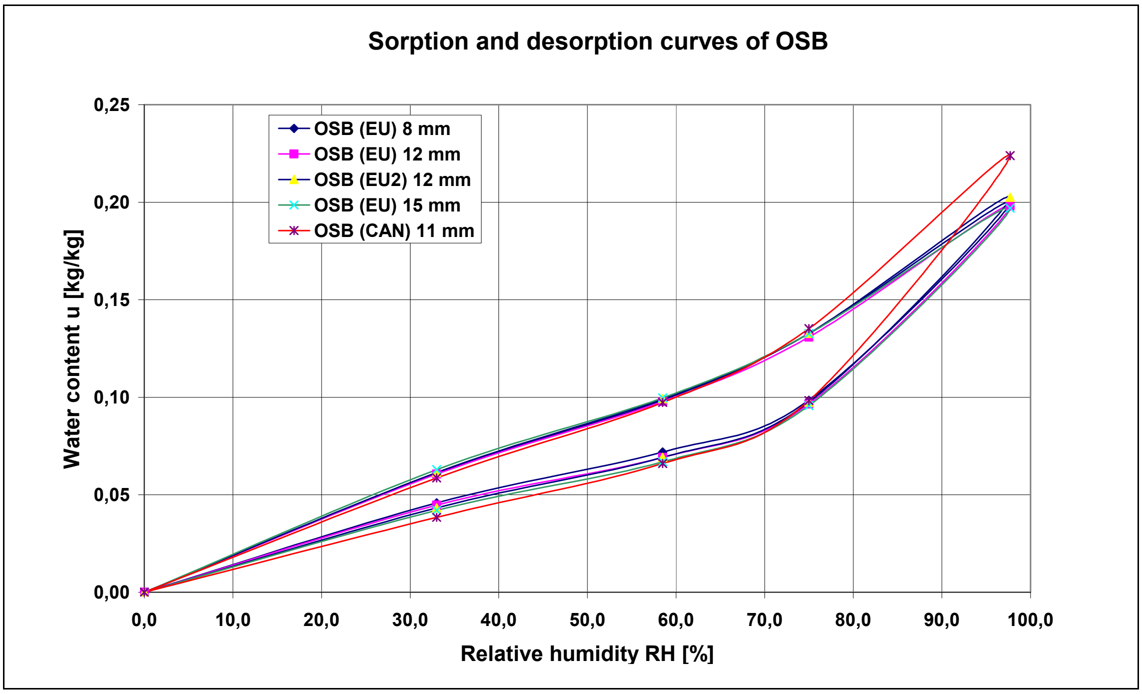


Figure 9. Sorption and desorption curves of the OSB products.

The shape of the curves is closely the same for all the products. Only in 98 % RH the moisture content of the Canadian OSB was about 2 % (weight) higher than that of the European products. Also the Canadian ply had slightly higher moisture content level in 98 % RH than the other products.

3.4 Capillary water absorption

3.4.1 Test method

Capillary saturation was measured by using experimental set up shown in Figure 10. The specimens had capillary contact with one surface, the edges were sealed and the top surface was open to room air. The capillary tests were carried out for 80 days and the specimens were weighted during the wetting. The results are presented as capillary water adsorption per surface unit.

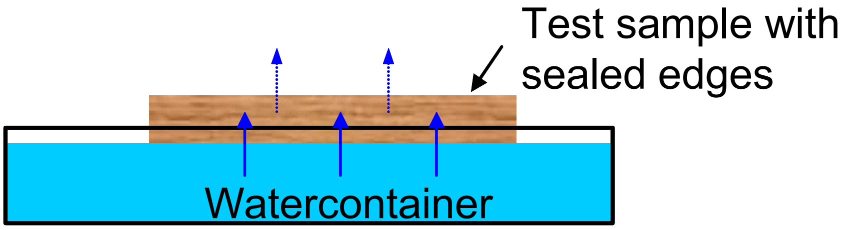


Figure 10. Experimental arrangement of capillary tests.

3.4.2 Specimen

Two equal rectangular specimens were taken from each of the nine products. The size of the specimen was 200 mm x 20d where d is board thickness. Before tests, the specimens were kept at indoor conditions (about +23 °C and 30 % RH).

3.4.3 Test results

Figure 11 presents the measured capillary suction profiles during the test period.

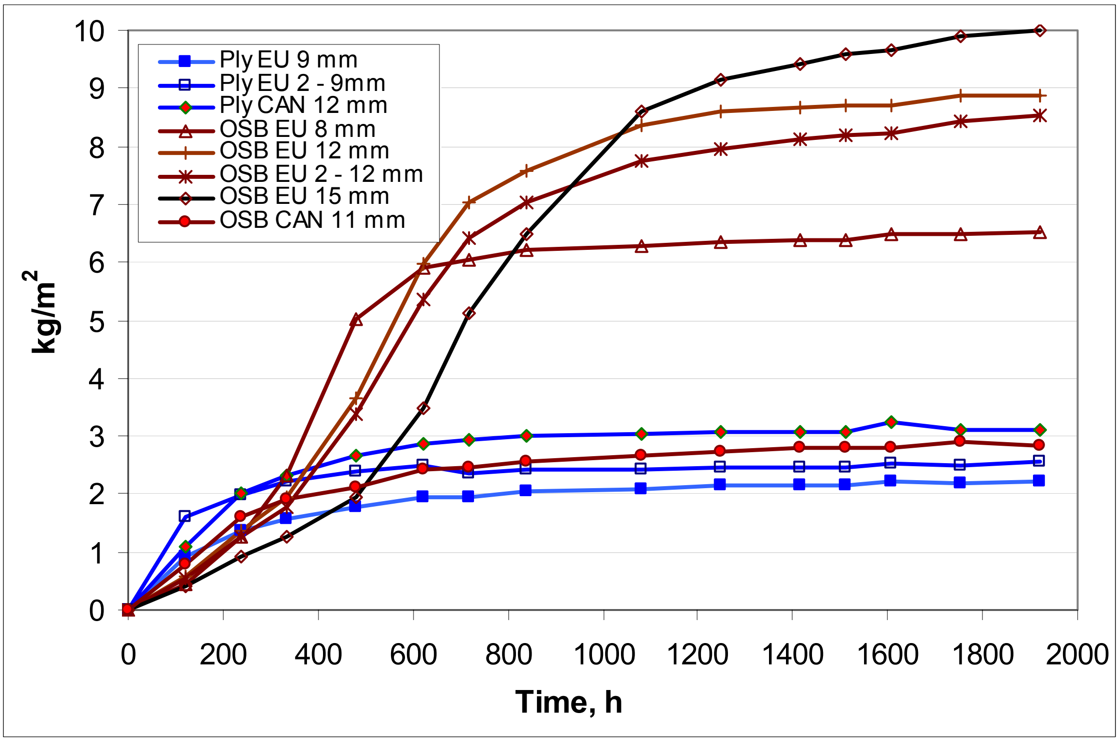


Figure 11. Capillary suction profiles during the test period.

Thicker products may contain more water than the thinner, and the board thickness is one variable in the following results.

During the first days (first weighing at about 100 h), the water absorption in the plywood products was 2–3 times higher than that in the OSB products. After the fourth day weighing, the declination of the curves (moisture flow rate) changes so that the water suction into OSB-products was the same or higher than that into the plywood products.

The profiles of the capillary suction curves were about the same for the European OSB products, while the wetting of the OSB CAN 11 mm product followed relatively well to that of the plywood products. During the four first days the OSB CAN had higher moisture level (0.8 kg/m^2) than the other OSB products (0.40 - 0.54 kg/m^2), but lower than the plywood products (0.9–1.6 kg/m^2).

After the first weighing during the wetting process, the slope of the suction curve was monotonously decreasing for all the European plywood products and the OSB CAN. In about five to six weeks these products had reached the level of their final moisture content that was 2.2–3.1 kg/m^2.

The capillary suction of the European OSB -products increased highly after about two weeks (350 h). Depending on product, after 2–3 weeks (350–550 h) from the beginning of the suction test, the amount of absorbed moisture in the European OSB products had exceeded that of the plywood products. After this strong wetting period (after 3 - 6 weeks from the beginning of the test) the suction decreased, but the mass of moisture of the 15 and 12 mm products increased till the end of the test period. The final moisture levels of the European OSB products were 6.5 - 10 kg/m^2 while that of the OSB CAN was only 2.9 kg/m^2.

Conclusions

OSB -products have more resistance against short period water contact with the board surface than the plywood products. This is probably due to the wax that the OSB boards have at least on the surfaces. Plywood products start to absorb water immediately after water contact, but the suction flow decreases till the final moisture level is reached.

The European OSB products that were used in the research had two phase suction profile. In the first phase the surface treatment resisted moisture absorption, but after that the suction increased and the capillary moisture flux reached the peak level after 2 - 4 weeks from the beginning of the water contact. After this peak the moisture flux decreased, but suction continued till the end of the 80 days wetting period. The only exception was the EU OSB 8 mm product that nearly reached the final moisture level during the test.

The capillary end moisture level of the European OSB products were 3 - 4 times higher than that of the plywood products, while the OSB CAN results were in the same level with the plywood values. Reasons for the behaviour of the Canadian OSB may be the glue or also the timber material. The glue of this OSB is phenolformaldehyde which is typically used also in plywood products.

The complex behaviour of the OSB that differs from that of a homogenous material should be taken into account also in the numerical simulations, probably by dividing the board thickness to different layers. Due to different wax content and direction of the wood grains, the edges of the boards have most probably different capillary properties than the surface layers. This makes it even more complicated to simulate the moisture absorption into OSB-boards under water contact.

3.5 Effect of moisture content on dimensional stability

Dimensional changes in different relative humidity measured by method based on EN 318 Fibreboard – Determination of dimensional changes with changes in relative humidity. Dimensional changes were measured also in capillary water contact and these results are presented in this section.

3.5.1 Specimen

Six rectangular specimens were taken randomly from each of the nine products. The size of the specimen was 200mm x 20d, where d is board thickness. Three specimens had been cut from both longitudinal and transversal panel direction. Before tests, the specimens were kept at indoor conditions (about +23 °C and 30 % RH).

3.5.2 Test method

Three different test sets were employed (Table 10). In each test set the specimen remained in the test chamber until the mass of the specimens had reached constant value. Dimensional changes were measured as a change of the thickness and the length of the board. Thickness was measured at three different points.

Table 10. Conditions used in the dimensional tests.

Set	Temperature	RH [%]	Duration [d]
A	20 °C	35	14
B	20 °C	65	17
C	22 °C*	87	35

* Deviate from the standard

3.5.3 Test results

The preliminary equilibrium measurement was made at 65 % relative humidity, so that the proportion of the observed dimensional change above and below this conditions could be seen.

Figure 12 presents relative change of board thickness and Figure 13 relative change of board length, compared to the thickness and length at RH 65 %. Figure 12 includes the results also from the capillary saturation tests.

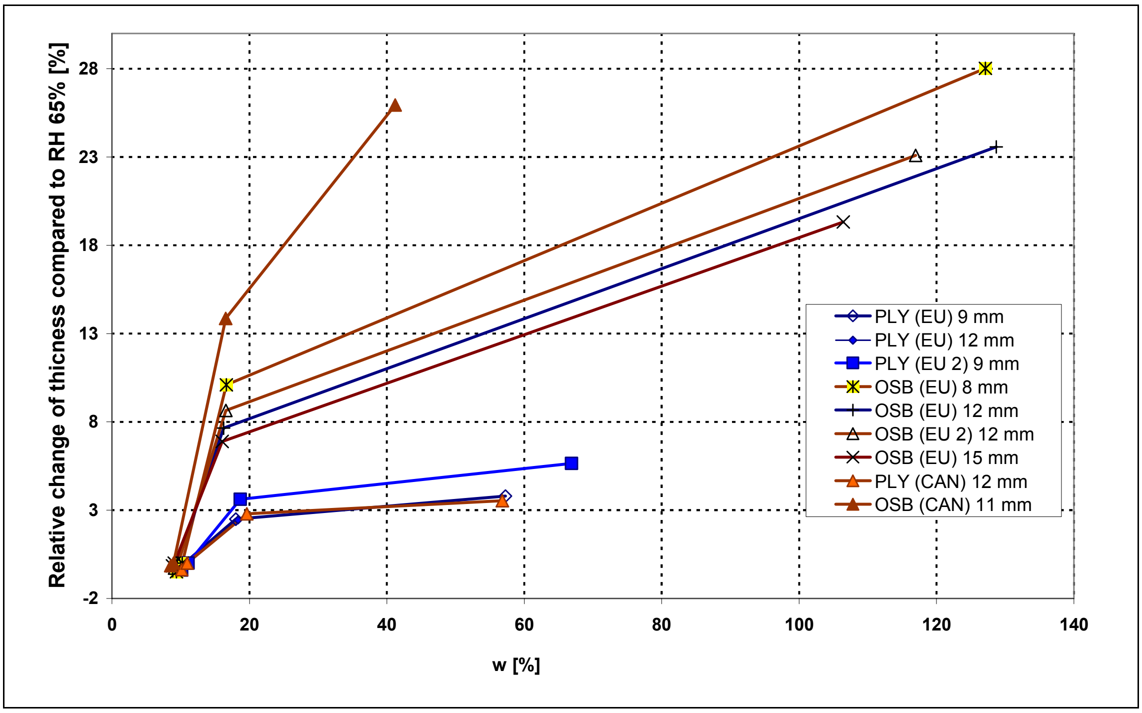


Figure 12. Relative change of the board thickness as a function of moisture content (% by weight).

The change of the OSB board thickness at 87 % RH was almost three times higher than that of the plywood boards. Also the spread of the results of the OSB products was significantly larger than that with the plywood products. Despite the relatively low capillary saturation level that the Canadian OSB had, the change of thickness of that product was highest in hygroscopic range and second highest in the capillary moisture content level. The relative change of OSB board thickness under capillary contact was in the range of 19–28 % and with plywood it was 3 to 6 %. With plywood products the difference between the dimensional change at hygroscopic area (87 % RH) and at capillary saturation level was relatively low, but with OSB products the capillary suction caused still significant increase in the board dimensions.

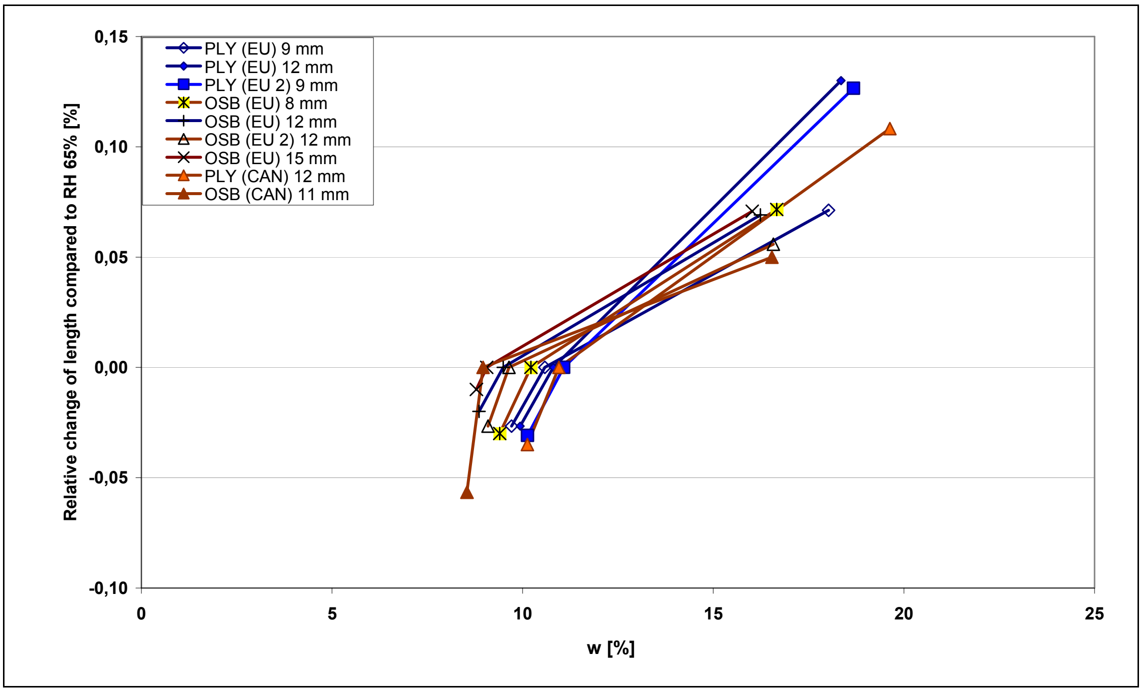


Figure 13. Relative change of board length as a function of moisture content (% by weight).

According to the sorption curves, the moisture content at 35 % should be about 5 %, but in these measurements it is still about 10 %, which means that the specimen hade not reached steady state conditions during the 14 days period and the results presented for RH 35 % are not valid. This shows again how long it takes for these materials to reach the equilibrium conditions. The test results for RH 65 %, RH 87 % and capillary conditions are reliable.

The relative change of board length was not presented for the capillary conditions, because the measurements contained some error sources caused by the bending of the boards. The dimensional change of the board length was very low, at the same level as in the hygroscopic range.

Conclusion

The effect of moisture on the change of the board length is not that high as that on the board thickness. The dimensional changes of the OSB and plywood products are quite different and these properties should be taken into account when designing the board fastening. Otherwise there is a risk to endanger the long time performance or durability of the sheathing. Especially this should be noticed with the OSB products that have high dimensional changes already in the hygroscopic area, i.e. in the conditions where the exterior sheathing boards typically are.

3.6 Drying efficiency

3.6.1 Objectives of the experiments

The objective of this experiment was to define the drying efficiency of structures through the exterior sheathing (wind barrier) under conditions that correspond to those in real applications. Moisture flow inside and out from the structure component was caused by partial vapour pressure difference, contributed by temperature gradient over the structure. The cold side air temperature could be settled so that both above and below freezing level conditions could be studied. In these experiments condensation was a prevailing condition on the inside surface of the wind barrier during the drying phase. The change of mass of the structure components were determined as a function of time and based on these measurements, the drying efficiency could be determined.

3.6.2 Test method

A simplified test method has been developed to study the drying efficiency of structures exposed to a temperature gradient and with high moisture content. In this test, the 1-dimensional intersection of the building envelope structure is sealed in a chamber, open from above to the cold side air. The warm side of the structure section is closed with a water vessel, which contains liquid water. This water vessel is bounded to the warm side air. Due to the horizontal installation the convection and water drainage effects are (almost) omitted and the drying of the structure is based only on diffusive moisture transport through the outer material layers (wind barrier etc.). The drying of moisture is monitored during the measuring period by weighing the whole installation frame of each structure section together with the initially set additional water. Experimental arrangement is presented in Figure 14.

The amount of the moisture dried from the structures was determined by periodically weighing each frame including the structure and the additional water. The result can be presented as a moisture flux (kg/(s m^2)) out from each structure and these fluxes represent the drying efficiency of the structures in the studied conditions. (Ojanen 1998, Ojanen & Salonvaara 2002, Ojanen et al. 2002, Seppänen & Säteri 2000)

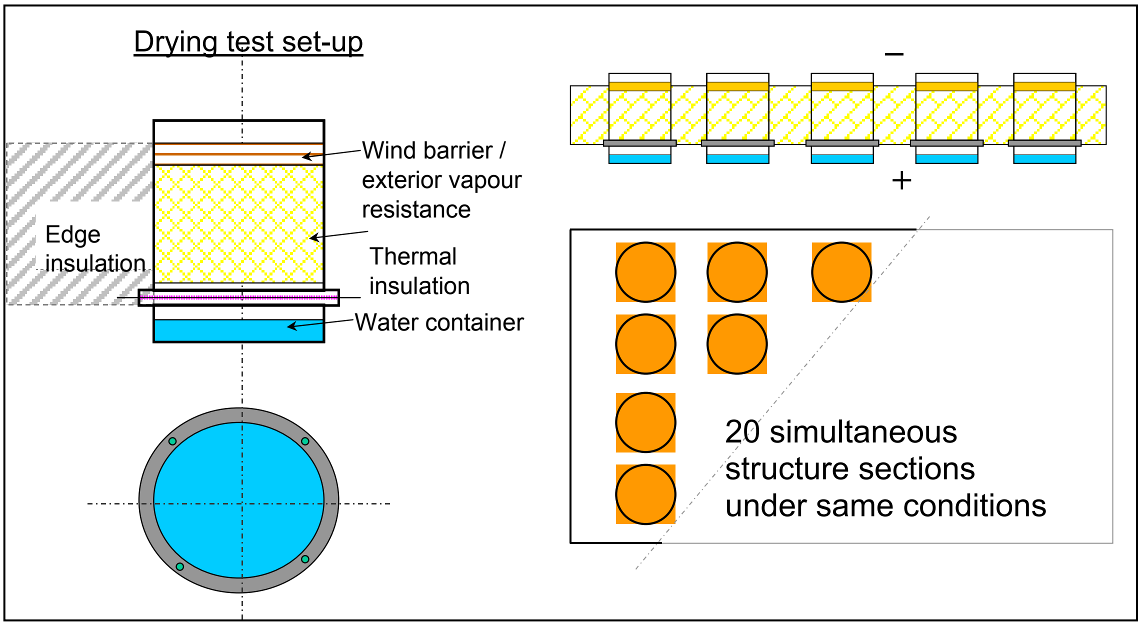


Figure 14. Experimental arrangement.

3.6.3 Test conditions

At the test cold side temperatures was -10 °C and +3 °C. Temperature conditions of the air spaces on both sides of the test structures were maintained constant during measuring period. The aim was to study the effect of temperature gradient and temperature conditions of the cold side of the structures on the drying efficiency. The warm side air temperature was maintained at +20 °C with less than ± 0.5 °C variation. The cold side temperature had less than ±1 °C variation from the set value, but temporary temperature peaks were possible during the melting of the cooling coil. The test periods are presented in Table 11. The relative humidity of the cold side air was not monitored.

Table 11. Test period used in the drying efficiency experiments.

Period type	**Warm side air temperature °C**	**Cold side air temperature °C**	**Length of test period days**
Freezing period	20	-10	50
Average heating period	20	+3	62

3.6.4 Specimen

Five OSB and four plywood products were studied in these experiments (Table 1). The diameter of the board sample was 315 mm and the thickness of the glass wool (20 kg/m^3) thermal insulation layer was 100 mm.

3.6.5 Experimental results

Figure 15 and Figure 16 present the measured total mass of the moisture dried out from the structure components during the two test periods (50 days under +20/-10 ºC and 62 days under +20/+3 ºC). The differences in the dried mass of moisture were caused only by the exterior sheathing that was made of plywood or OSB.

In all the cases the drying was more efficient when the cold side temperature was higher. Higher temperature level means higher possible partial vapour pressure difference (drying potential) over the exterior sheathing. Other reason is that under freezing conditions the condensate freezes on the inside surface of the wind barrier board and forms an additional vapour resistance. In addition to the vapour permeability, the thickness of the board has an effect to drying efficiency.

Under the experimental conditions the dried mass of moisture was significantly lower through OSB exterior sheathing than through plywood sheathing. Good drying efficiency is needed against accidental moisture loads that may exceed those used as the basic design loads. The decisive property to define the drying efficiency of a structure in cold climates is the vapour permeability of the exterior sheathing layer under realistic conditions.

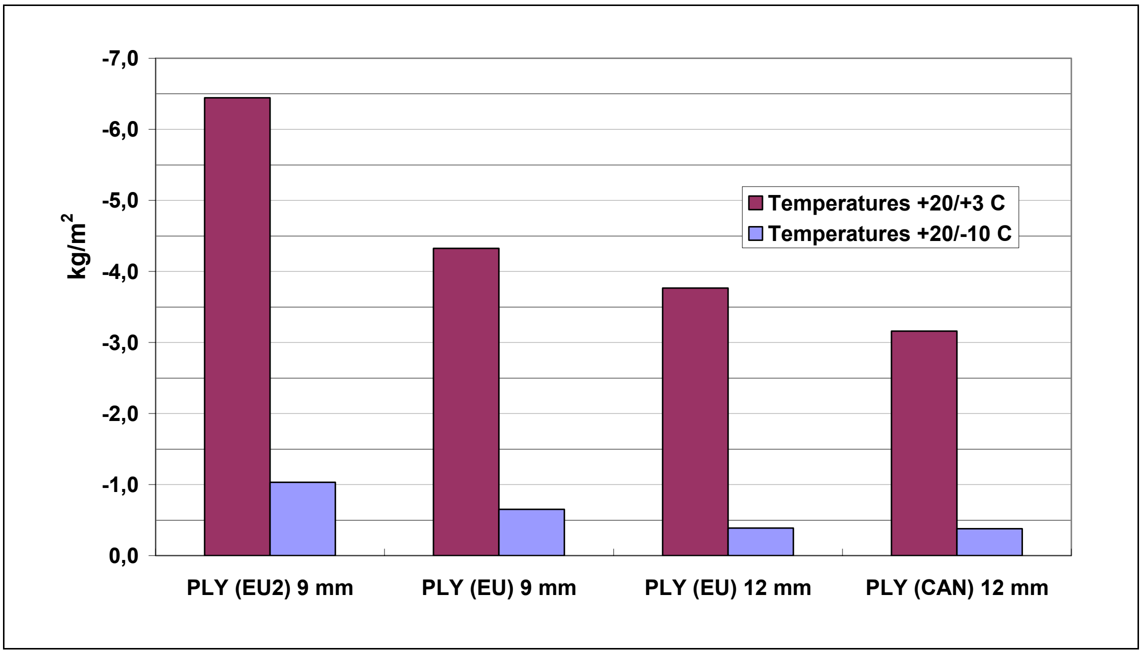


Figure 15. Total mass of dried out moisture from test structures having plywood as exterior sheathing. The test periods had 50 days under freezing and 62 days above freezing conditions.

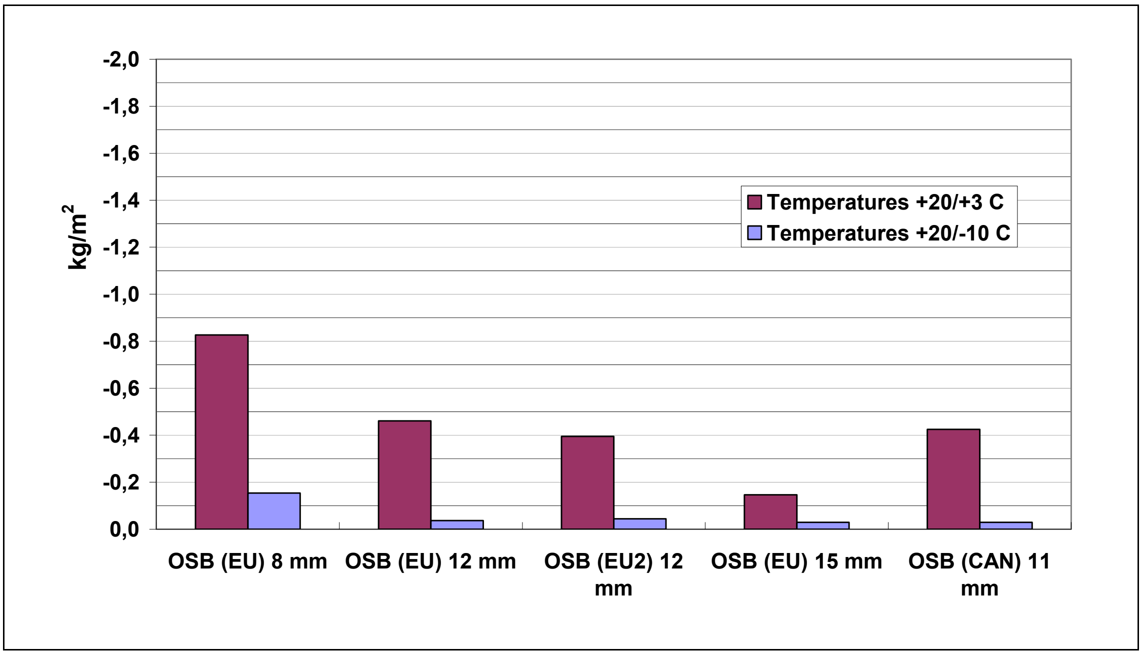


Figure 16. Total mass of dried out moisture from test structures having OSB exterior sheathing. The test periods had 50 days under freezing and 62 days above freezing conditions.

3.7 Correlation of the drying experiments with conditions in practice

The drying experiments were carried out using fixed conditions and test set-up. The objective was to study the relative drying efficiency of the studied structure components under similar conditions. These conditions are closer to reality than, for example, those used in the determination of the water vapour permeability (cup method). The drying experiments are carried out using temperature differences and temperature levels that correspond better to real building conditions.

3.7.1 Differences between experiments and real conditions

Some differences between conditions in practice and in the experiments still exist.

The experiments have close to stabile conditions, while the temperature and partial vapour pressure varies strongly in natural climate. During drying the inside surface of the exterior sheathing is typically under condensation conditions. In the experiments this is a prevailing condition, and in practice this is typical during winter, which is the often worst case for drying. Solar radiation may significantly change the case in practice. The low drying efficiency winter conditions are those that are most interesting and this difference has probably not too much effect on the results.

The measured temperature variation on the inside surface of the exterior sheathing was relatively high. Table 12 presents the average temperatures of the measured cases. There was a significant variation, over ±0.5 ºC, between the measured values in cases where the exterior thermal resistance should have been about the same. The temperature measurements in such case are not accurate enough to give reliable values to solve the exact partial vapor pressure level on the warm side of the sheathing. Due to these uncertainties the results should not be used to solve the apparent vapour permeability of the material.

Table 12. Measured average temperatures at the inside surface of the exterior sheathing during the experiments, average of all measured values, cold side and warm side temperatures.

	PLY (EU) 9 mm	PLY (EU) 12 mm	PLY (EU2) 9 mm	OSB (EU) 8 mm	OSB (EU) 12 mm	OSB (EU2) 12 mm	OSB (EU) 15 mm	OSB (CAN) 12 mm	OSB (CAN) 11 mm	Aver	T_{cold}	T_{warm}
d, mm	9	12	9	8	12	12	15	12	11			
$T_s(-10)$	-6.27	-4.87	-5.74	-5.49	-6.55	-5.91	-5.59	-5.42	-5.87	-5.75	-10.74	19.42
$T_s(+3)$	4.60	5.71	4.72	5.42	3.98	5.71	5.24	5.67	4.76	5.09	3.50	19.58

The relative humidity of the exterior cold side air had a relatively constant value, but it was not controlled, and the level was different, typically lower, than in real climate conditions. This again causes differences between the experiments and the real structures.

The effect of the thermal resistance (or U-value) of the structure on the drying was studied by comparing two structures with different U-values under the test conditions. In the experiments the thermal insulation (glass wool) thickness was 100 mm, which corresponds to about 0.40 W/(K m^2) U-value. In Finland the Building code sets requirements for the maximum U-value of a wall in new buildings which is 0.25 W/(K m^2).

The effect of the U-value was studied using the following assumptions. There is continuous condensation on the inside surface of the exterior sheathing. The cold side air has 30 % relative humidity, which was typical level also in the experiments. The thermal effect of the phase change was assumed to be the same for both the cases. The U-value of the structure used in the experiments was 60 % higher than that according to the building regulations. Two cases with different temperatures were solved, +20 / -10 ºC and +20 / +3 ºC. The heat transfer coefficient on the cold side surface had two values, it was assumed to be 25 W/(K m^2) (corresponding to typical outdoor level) or 5 W/(K m^2) (low value when the surface is sheltered from convection flow representing lower limit value in the experiments).

Table 13. Relative effect of U-value (U-values 0.25 and 0.40 W/(K m^2)) on the partial vapour pressure difference over the exterior sheathing under different temperature conditions and with different heat transfer coefficients on the cold surface.

	(pv,s *(U=0,40)*-pv,out)/(pv,s *(U=0,25)*-pv,out)	
α_{out},W/(K m^2)	+20 /-10 ºC	+20 / +3 ºC
25 W/(K m^2)	-2.0 %	1.7 %
5 W/(K m^2)	9.5 %	5.3 %

The moisture flow through the exterior sheathing depends on the partial vapour pressure difference over this material layer and on the vapour permeability of the material under the prevailing conditions. The results of the numerical analysis are presented in Table 13. According to the analysis, the effect of U-value on the partial vapour pressure difference over the exterior sheathing (9 mm plywood) under test conditions was quite low. When the heat transfer coefficient of the cold side surface was 25 W/(K m^2), the relative effect of U-value was about ± 2 %. Even when the heat transfer coefficient of the surface was lower, 5 W/(K m^2), the relative effect remained below 10 %.

The vapour permeability of the exterior sheathing depends on the moisture content of that layer. Both in real climate case and in the experiments, there are condensation conditions on the inside surface. The main difference is with the outdoor air relative humidity, which is typically higher than that used in the tests. This causes lower partial vapour pressure difference than in the experiments, but the moisture content of the sheathing can be slightly higher, which means higher vapour permeability of the layer.

3.7.2 Conclusions

When the exterior sheathing board is under freezing conditions, the drying efficiency of the structure was very low. During 50 days under +20 / -10 ºC temperature conditions the OSB sheathing allowed only 30 g/m^2 to 150 g/m^2 drying, while the corresponding figures for otherwise similar plywood structures were in the range of 380 to 1030 g/m^2 During the next 62 days under +20 / +3 ºC temperature conditions, the dried out moisture was with OSB sheathing in the range of 150–830 g/m^2 and with the plywood products 3160–6440 g/m^2.

The drying experiments were not meant to simulate real case drying of building components in an accurate level. The objective was to determine the relative drying efficiency of the test structures under controlled conditions that are close to realistic. The drying efficiency was studied under temperature gradient when the exterior sheathing temperature was in freezing zone or when the temperature level corresponded to typical conditions during the heating period. Also the continuous free moisture flow from the water source simplifies the case from real situations, where the moisture is typically absorbed in the materials or it flows through the inside sheathing with some limited mass flow level.

The results give adequate information about these effects and they represent in reasonable level the drying efficiency and in a good level the relative dying efficiency of the structures used in the experiments. The effect of the thickness of the thermal insulation on the drying is quite limited in the experimental conditions and taking into account the accuracy and objectives of the experiments, there is no reason to convert the result in order to try to correspond better to realistic structures.

3.8 Wetting and drying experiments

The objective in these wetting and drying experiments was to determine how quick the products will dry after water contact at constant conditions. These experiments represent cases where the sheathing boards get wet on the building site before or after installation.

3.8.1 Test method

First test specimens were immersed into water so that 3–4 mm of the specimen was below the water surface. Duration of the wetting process was 24 hours. After wetting, specimens were held for 10 minutes at 45 degree position to drain water from the surfaces. After weighting specimen were placed in constant conditions, temperature 23 °C and RH 40 %. The specimens were weighted periodically during the test procedure so that the moisture profiles could be determined.

3.8.2 Specimen

Two rectangular (200 mm x 200 mm) specimens were taken from each of the nine products. In test set A all the four edges of the specimen were sealed with wax and in the test set B only three edges were sealed. Test set B represents typical exterior board installation with open joints. The ratio of the open edge and board surface area is in the test set B about two times higher than that with full size 1.2 m x 2.4 m boards having all the edges unsealed.

3.8.3 Experimental results

Figure 17 presents the change of the mass of moisture in the test specimens (Set A) having all four edges sealed with wax and Figure 18 that with test specimens (Set B) having three edges sealed and one open.

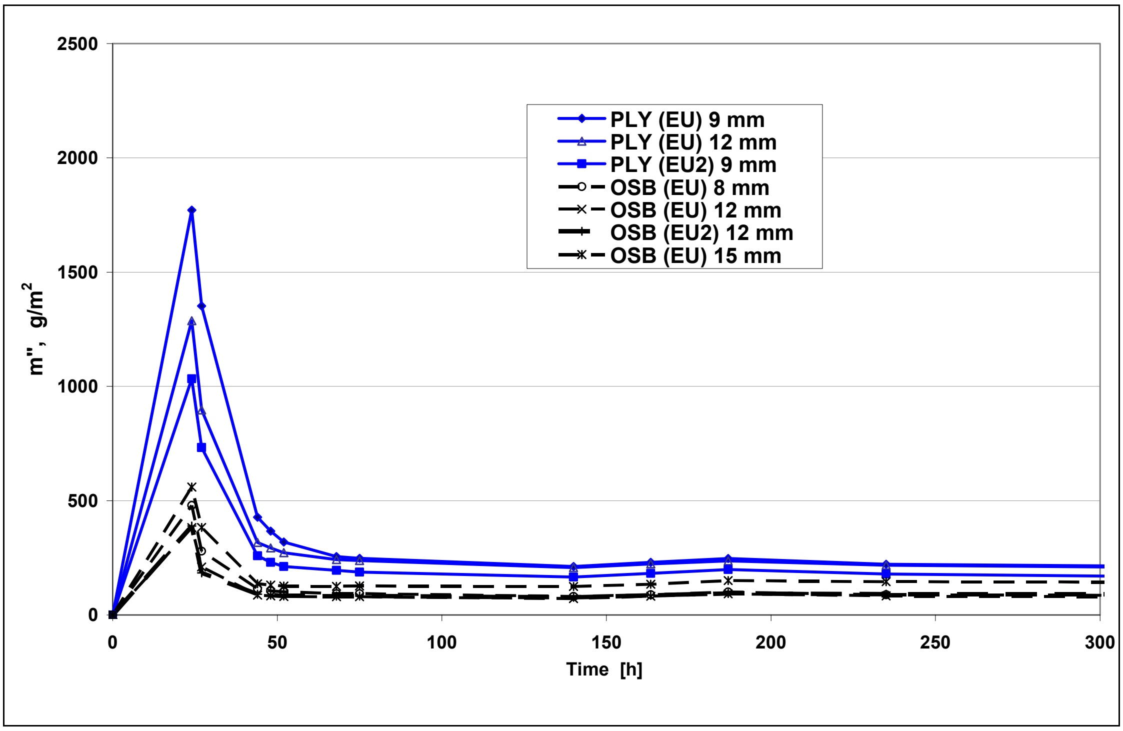


Figure 17. Change of the mass of moisture in the test specimens with sealed edges.

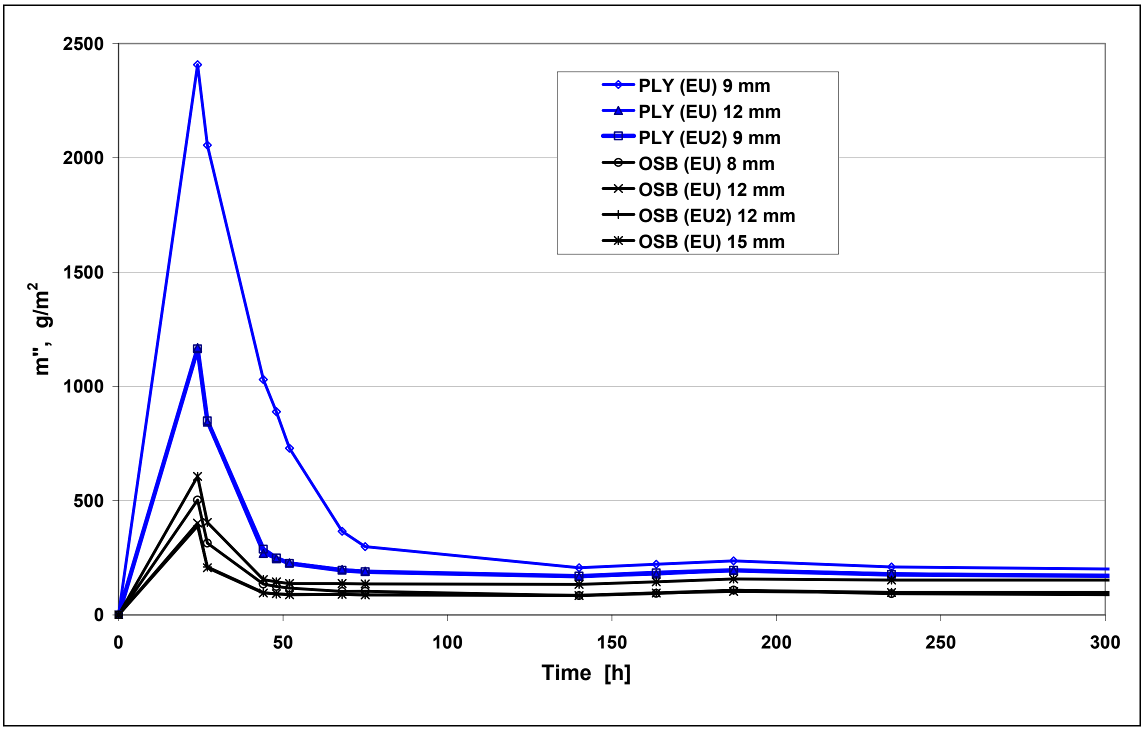


Figure 18. Change of the mass of moisture in the test specimens with three sealed and one open edge.

Plywood absorbed significantly more moisture than OSB during the first 24 hours when under capillary contact with water. This could be seen also in the capillary saturation tests. Also the effect of one open edge on the wetting of test samples was higher with plywood than with OSB.

The drying of the test specimens from the absorbed moisture level was slightly faster with OSB. After the next 24 hours all the OSB samples had dried close to the final moisture content level. For plywood it took about 8 to 36 hours more time to reach the end moisture content level, which was due to the higher moisture content after the suction period. One of the plywood test samples that had one open edge absorbed close to five times more moisture than the OSB boards during the water contact and it also had the longest drying period.

Due to the different kind of surface (wax) layers that the OSB boards have, the capillary water absorption into the board during temporary contacts with water was very slow compared to that of plywood. Resistance against wetting is important during the construction period when the exterior sheathing is not yet protected against rain.

3.8.4 Observation about the effect of surface coating

Simple observations were taken to study the effect of surface coating or surface layers on the wetting process during contact with water. A drop of water was placed on the surface of European plywood and OSB products and the suction of water was monitored by visual inspection. The results are presented in Figure 19.

This gives a qualitative representation about the surface wetting. All the free water was absorbed in the plywood during the first minute, but there was no sign of capillary absorption into OSB for several minutes. This shows the effect of the slightly water repellent surface of OSB and it partly explains the results of the wetting tests.

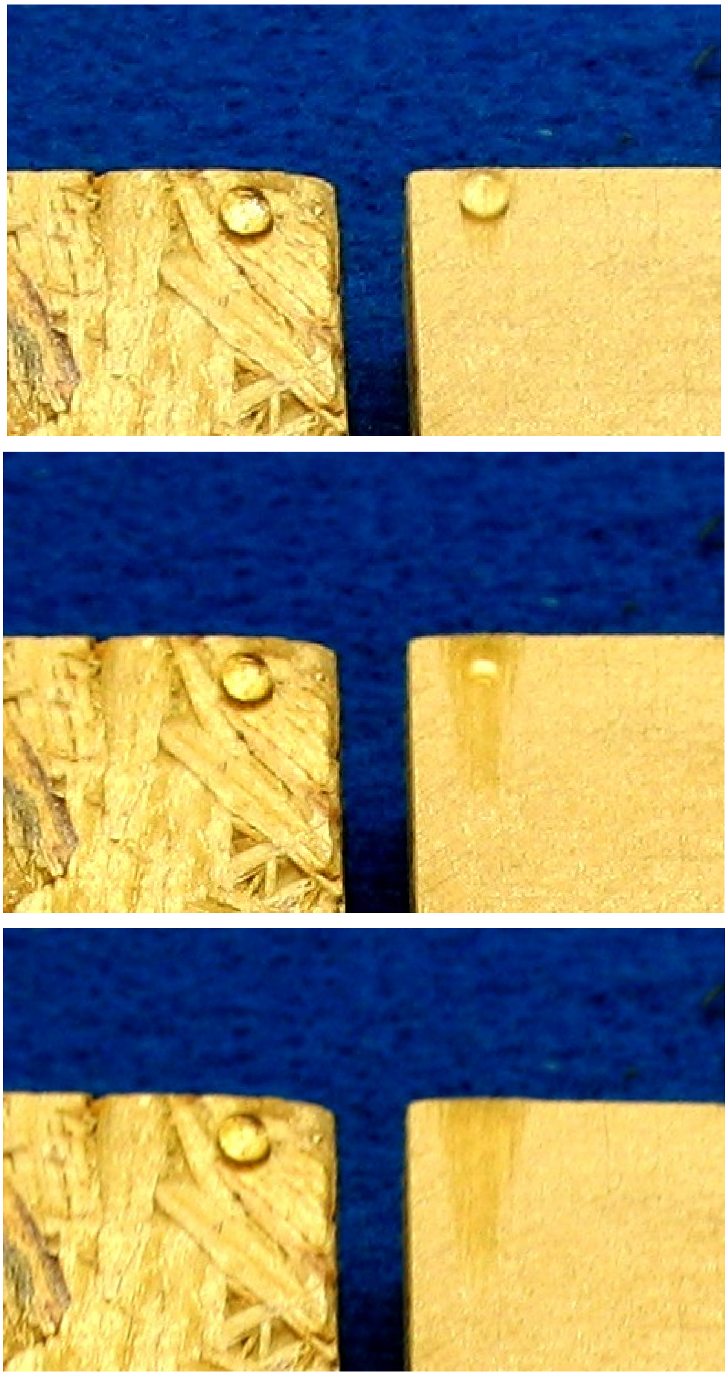


Figure 19. Water drop on the surface of OSB (left) and plywood (right) after about 2 s (top), 30 s (middle) and 60 s (bottom) from the first contact with water.

4. Summary and conclusions about the moisture performance characteristics of the studied OSB and spruce plywood products

Plywood and OSB are typical building boards that are made of timber and have good structural strength. Plywood consists of rotary-cut veneers which are glued together as layers. OSB is made of oriented wood chips and glue that are compressed. The glue mostly consists of different components in surface and inner layers of the product. There can also be wax surface treatment to protect the OSB product against water. The main differences among the products are thus the wood raw material, the structure (composite or plied), type of the glue and the production process. In this research the product properties are not studied and listed in a detailed way and the products are only mentioned as codes referring to product type (OSB or plywood) and according to origin (European or Canadian).

All the products used in this research were meant to be used as **exterior sheathing** boards. In Northern Europe this layer is also called as **wind barrier**.

This research was carried out to experimentally determine the material properties and performance characteristics that have effect on the moisture performance of building structures where OSB (Oriented Strand Board) or spruce plywood are applied as exterior sheathing boards. Four plywood products, three European (Finnish) and one Canadian, and five OSB products, four European and one Canadian, were used in these experiments. The density of the plywood products was in the range of 400 - 450 kg/m^3 and that of OSB products 570 -600 kg/m^3. The tests were applied according to standard requirements when such standard exists. Additional tests and performance experiments were developed and carried out to better understand the moisture behaviour of the products.

Air permeability is an important material property of the exterior sheathing when this material layer is meant to protect the thermal insulation against wind washing. Several countries, including Finland, have set required or recommended value of air permeability factor in their building code. For example, in Norway the requirement for the air permeability of the installed exterior sheathing layer must be less than 0.05 m^3/(m^2 h Pa), about $1.4 \cdot 10^{-5}$ m^3/(m^2 · s · Pa). In Finland the lowest recommended value for a wind barrier product is $1.0 \cdot 10^{-5}$ m^3/(m^2 · s · Pa) when other structural means are not used to avoid convection over the corner structures. All the tested materials satisfy these requirements and recommendations. There was a large variation among the air tightness levels of these products, which is probably due to the structure of the material and possible air leakage routes through the whole product.

Sorption/desorption curves were determined between 33 % and 98 % RH. It took a long time, especially with OSB, to reach the final moisture content level.

Capillary water absorption experiments showed also how the products differed from each other. When in contact with water, all the plywood products absorbed water faster than OSB -products during the first four days. Moisture absorption into plywood decreased after this initial period and the final moisture content level was reached in a few weeks. Moisture absorption into four OSB-products out of five started to increase significantly after 1–2 weeks and the moisture content level of these products exceeded that of plywood's after 2–3 weeks. The final moisture content level of these four OSB products was about 2–5 times higher than that of plywood products or the one OSB. The reason for such two-phase capillary absorption may be caused by the different components of glue and possible wax in surface and inside parts of OSB. The one OSB product had the same glue as the plywood products. This would mean a significant dependence of material properties on the glue type and it would be one of the items to take into account in product development.

The dimensional stability of the product has an effect on the air and moisture tightness, thermal performance and even on the strength of the structure. High swelling of the material could be detected mainly in the board thickness. The relative dimensional change on the longitudinal direction was significantly lower than that of the thickness.

The relative change of OSB board thickness under capillary contact was in the range of 19–28 % and with plywood it was from 3 to 6 %. Most of the swelling of plywood boards took place in the hygroscopic area, but about half of the swelling of the OSB boards took place between 87 % RH and the capillary saturation conditions.

The possible change of board thickness under wet conditions has to be recognised when designing the board fastening.

Water vapour permeability values were determined in four relative humidity range conditions giving the result as a function of the relative humidity of the materials. In addition to the dry and wet cup conditions two additional humidity conditions were applied in the tests.

The vapour permeability of both OSB and plywood were in a relatively low level under dry conditions, but the level increased a lot after certain relative humidity level. There was a significant difference between the products in this respect. The vapour permeability level of plywood was under 80 / 58 % RH condition measurements from 5 to 11 times higher than those measured under dry cup conditions for the same product. With OSB these values were only about 1.2–3 times higher than under dry cup conditions. When the relative humidity test conditions were 97 %/ 72 % RH, the vapour permeability of OSB had increased to be about 4 to 9 times higher than in the dry cup tests, while the plywood vapour permeability level was 12 to 20 times higher, depending on the product.

The relative humidity conditions of the exterior sheathing are typically high and the wet cup conditions correspond best to them. One set of experiments were done using relative humidity conditions 80 % / 58 % RH, which represents to high, but still safe moisture conditions. The first sign of biological deterioration (typically mould) can be found in wood having long period under relative humidity conditions exceeding 80 %. In cold and moderate climates the temperature level of the exterior sheathing is most time of the year lower than +20 ºC, and the critical RH limit increases with lower temperatures. The vapour permeability determined under 80 % / 58 % RH humidity range was about the same as that derived from wet cup tests. The value from wet cup test gives a good approximation for the level of vapour permeability under moisture safe conditions.

Some countries have regulations for the maximum water vapour resistance of the exterior sheathing. In Sweden this limit value is $2.7\cdot 10^{+9}\,\mathrm{m^2sPa/kg}$ and in Norway it is $9.6\cdot 10^{+9}\,\mathrm{m^2sPa/kg}$. According to the results determined under 80 % / 58 % RH conditions, only two of the products (9 mm spruce plywood boards) would satisfy the Swedish requirements.

In Finland, OSB is not commonly well known, and even some standards present inaccurate values for the vapour permeability of the product under wet cup conditions. The level of vapour permeability must be known to be able to design moisture safe structures. Inaccurate or false values may lead into severe moisture performance problems. The vapour permeability level of the exterior sheathing board gives an idea of the drying efficiency, but the overall moisture performance of a structure depends on all the design parameters and moisture load conditions.

One thing that may easily cause errors in the determination of the vapour permeability is the lack of so called blind cup in the cup measurements. When a material has low vapour permeability together and high hygroscopic moisture absorption capacity, it takes a long time to reach really stabile moisture flow conditions that are needed to accurately solve the vapour permeability. A blind cup would clearly show when stabile conditions have been reached, but unfortunately this is not required in the latest standards.

The drying experiments confirmed what was found in the vapour permeability measurements. When the exterior sheathing board is under freezing conditions, the drying efficiency of the structure is very low. With OSB sheathing the dried out mass of moisture during 50 days under +20 / -10 ºC of warm and cold side air temperature conditions varied between as low as 30 g/m^2 to 150 g/m^2 while the corresponding figures for otherwise similar plywood structures were in the range of 380 to 1030 g/m^2, depending on the exterior sheathing product. After this experiment, during the next 62 days, the dried out moisture with OSB sheathing was in the range of 150–830 g/m^2 and with the plywood product 3160–6440 g/m^2. These results represent the drying efficiency of structures with the studied exterior sheathing boards under such conditions that correspond closely to real structures having excess of moisture in cold and moderate climates during the heating period.

Resistance against wetting (water repellence) is an important property especially during the construction period when the exterior sheathing is not yet protected against rain. Due to the different kind of surface layers that the OSB boards may have, the capillary water absorption into the board can be significantly lower than that into plywood during temporary contacts with water. The surface coatings may probably also be one reason for the low vapour permeability and drying efficiency of OSB products. During long (four days or more) periods of water contacts, the moisture flow rate into OSB exceeds that into plywood.

One product can not have all the optimum properties for the use as exterior sheathing. The product is always a compromise between different properties like vapour permeability, water resistance, dimensional stability, structural strength etc. These properties should be taken into account in the product development of materials and their applications in building structures to be used in different climate conditions and moisture loads. (Simonson & Ojanen 2000)

5. Recommendations for further research and product development

The results derived in this research give a good overview of the moisture performance properties of OSB and plywood products. These products have possibilities to be developed further to meet with the requirements that different indoor and outdoor climate loads cause. Also the safety factor against accidental moisture loads should be considered to some extent.

The main challenge would be in developing such structures and design principles that would guide the practitioners to the most suitable, moisture safe, energy efficient and sustainable systems. This work would require worldwide collaboration of wood scientist and wood industry.

References

Kumaran, K. 1996. Final Report Volume 3, Task 3: Material properties Heat, Air and Moisture Transfer in insulated Envelope Parts. Belgium. ISBN 90-75741-01-4

Mukhopadhyaya, P., Kumaran, K. Tariku, F. & van Reenen, D. 2003. Long-term performance predict the moisture management performance of wall systems as a function of climate, material properties, etc. through mathematical modelling. Final report from task 7 of MEWS project at the Institute for Research in Construction. Canada: IRC.

Ojanen, T. 1993. Criteria for the Hygrothermal Performance of Wind Barrier Structures. Proceedings of the 3rd Symposium Building Physics in the Nordic Countries. Copenhagen Sept. 13–15, 1993. Pp. 643–652.

Ojanen, T. 1998. Improving the drying efficiency of timber frame walls in cold climates by using exterior insulation. Proceedings of the Thermal Performance of the Exterior Envelopes of Buildings VII, ASHRAE/DOE/BETEC/ORNL Conference, Dec. 6.–10., 1998. Clearwater Beach. Pp. 155–164.

Ojanen, T., Kokko, E., Salonvaara, M & Viitanen, H. 1997. Moisture performance of structures with plywood sheathings. [Havuvanerirakenteiden kosteusteknisen toiminnan perusteet]. VTT Research Notes 1870. Espoo. 90 p. + app. 2 p. ISBN 951-38-5169-9. (In Finnish)

Ojanen, T. & Salonvaara, M. 2002. Structures with high drying efficiency and resistance against rain penetration [Kuivumiskykyiset ja sateenpitävät rakenteet]. VTT Research Notes 2168. Espoo: VTT. 66 p. + app. 3 p. (In Finnish). ISBN 951-38-6091-4; 951-38-6092-2. http://www.vtt.fi/inf/pdf/tiedotteet/2002/T2168.pdf

Ojanen, T., Salonvaara, M. & Simonson, C. 2002. Integration of simplified drying tests and numerical simulation in moisture performance analysis of the building envelope. Proceedings of the 6th Symposium on Building Physics in the Nordic Countries. Trondheim, 17–19 June 2002. Trondheim: Byggforsk; SINTEF; NTNU. Pp. 151–158.

Simonson, C. & Ojanen, T. 2000. Moisture performance of buildings with no plastic vapour retarder in cold climates. Healthy Buildings 2000. Espoo, FI, 6–10 Aug. 2000.

Seppänen, O. & Säteri, J. (Eds.). 2000. Vol. 3: Microbes, Moisture and Building Physics. Healthy Buildings 2000. Espoo, FI, 6–10 Aug. 2000. Espoo: Finnish Society of Indoor Air Quality and Climate (FiSIAQ). Pp. 477–782.

Viitanen, H., Ritschkoff, A., Ojanen, T. & Salonvaara, M. 2003. Moisture conditions and biodeterioration risk of building materials and structure. Proceedings of the 2nd International Symposium ILCDES 2003 Integrated Life-time Engineering of Buildings and Civil Infrastrucures. Kuopio, 1–3 Dec. 2003. Espoo: RIL, VTT, CIB, RILEM, IABSE, ECCE, ASCE. Pp. 151–156.

Appendix A:

TABLE A1. Water vapour permeability (from cup method) at 22 °C RH(1) = 0 %, RH(2) = 50 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN δ [kg/m·s·Pa x 10^{-12}]**	**MAX δ [kg/m·s·Pa x 10^{-12}]**	**MEAN δ [kg/m·s·Pa x 10^{-12}]**
Plywood EU	9	424	0.40	0.47	0.43
Plywood EU	12	434	0.36	0.44	0.42
Plywood EU 2	9	451	0.36	0.53	0.45
OSB	8	603	0.99	1.13	1.08
OSB EU	12	573	0.78	1.30	1.09
OSB EU 2	12	590	0.75	1.22	1.01
OSB EU	15	586	0.76	1.08	0.88
Plywood CAN	12	395	0.68	0.84	0.75
OSB CAN	11	579	0.40	0.95	0.55

TABLE A2. Water vapour resistance (from cup method) at 22 °C, RH(1) = 0 %, RH(2) = 50 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN Z [m^2·s·Pa/kg x 10^9]**	**MAX Z [m^2·s·Pa/kg x 10^9]**	**MEAN Z [m^2·s·Pa/kg x 10^9]**
Plywood EU	9	424	19.2	22.7	21.2
Plywood EU	12	434	27.9	33.9	29.8
Plywood EU 2	9	451	16.2	23.4	19.3
OSB	8	603	7.33	8.42	7.68
OSB EU	12	573	9.56	16.0	11.8
OSB EU 2	12	590	9.84	16.1	12.5
OSB EU	15	586	14.4	20.4	18.0
Plywood CAN	12	395	19.6	15.8	17.8
OSB CAN	11	579	12.0	28.8	23.2

TABLE A3. Water vapour resistance factor (from cup method) at 22 ℃, RH(1)=0% RH(2)=50%.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m³]**	**MIN μ [-]**	**MAX μ [-]**	**MEAN μ [-]**
Plywood EU	9	424	414.14	489.87	456.67
Plywood EU	12	434	439.92	535.46	470.10
Plywood EU 2	9	451	369.79	533.83	441.86
OSB	8	603	171.50	197.15	179.70
OSB EU	12	573	149.82	250.25	184.97
OSB EU 2	12	590	159.32	260.88	202.23
OSB EU	15	586	181.51	257.30	225.98
Plywood CAN	12	395	232.64	289.10	262.29
OSB CAN	11	579	205.00	494.03	396.93

TABLE A4. Water vapour diffusion equivalent air layer thickness (from cup method) at 22 ℃, RH(1) = 0 %, RH(2) = 50 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m³]**	**MIN S_d [mm]**	**MAX S_d [mm]**	**MEAN S_d [mm]**
Plywood EU	9	424	3727	4409	4110
Plywood EU	12	434	5411	6586	5782
Plywood EU 2	9	451	3143	4538	3756
OSB	8	603	1423	1636	1492
OSB EU	12	573	1858	3103	2294
OSB EU 2	12	590	1912	3131	2427
OSB EU	15	586	2813	3988	3503
Plywood CAN	12	395	3094	3845	3488
OSB CAN	11	579	2337	5632	4525

TABLE A5. Water vapour permeance (from cup method) at 22 °C, RH(1) = 0 %, RH(2) = 50 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN 1/Z [Perm]**	**MAX 1/Z [Perm]**	**MEAN 1/Z [Perm]**
Plywood EU	9	424	0.77	0.91	0.82
Plywood EU	12	434	0.53	0.63	0.60
Plywood EU 2	9	451	0.75	1.09	0.93
OSB	8	603	2.08	2.38	2.29
OSB EU	12	573	1.10	1.84	1.54
OSB EU 2	12	590	1.09	1.79	1.47
OSB EU	15	586	0.86	1.21	1.00
Plywood CAN	12	395	0.89	1.10	0.98
OSB CAN	11	579	0.61	1.47	0.84

TABLE A6. Water vapour permeability (from cup method) at 22 °C, RH(1) = 0 %, RH(2) = 50 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN [Perm-inch]**	**MAX [Perm-inch]**	**MEAN [Perm-inch]**
Plywood EU	9	424	0.27	0.32	0.29
Plywood EU	12	434	0.25	0.30	0.29
Plywood EU 2	9	451	0.25	0.36	0.31
OSB	8	603	0.68	0.77	0.74
OSB EU	12	573	0.53	0.89	0.75
OSB EU 2	12	590	0.51	0.84	0.69
OSB EU	15	586	0.52	0.74	0.60
Plywood CAN	12	395	0.47	0.58	0.51
OSB CAN	11	579	0.27	0.65	0.38

TABLE A7. Water vapour permeability (from cup method) at 22 °C, RH(1) = 58 %, RH(2) = 80 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN δ [kg/m·s·Pa x 10^{-12}]**	**MAX δ [kg/m·s·Pa x 10^{-12}]**	**MEAN δ [kg/m·s·Pa x 10^{-12}]**
Plywood EU	9	424	4.50	5.14	4.67
Plywood EU	12	434	2.91	3.97	3.18
Plywood EU 2	9	451	3.83	4.35	4.08
OSB	8	603	1.37	1.59	1.51
OSB EU	12	573	1.05	1.70	1.31
OSB EU 2	12	590	0.95	2.00	1.60
OSB EU	15	586	0.58	0.88	0.75
Plywood CAN	12	395	3.62	4.29	3.70
OSB CAN	11	579	1.28	1.78	1.59

TABLE A8. Water vapour resistance (from cup method) at 22 °C. RH(1) = 58 %, RH(2) = 80 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN Z [m^2·s·Pa/kg x 10^9]**	**MAX Z [m^2·s·Pa/kg x 10^9]**	**MEAN Z [m^2·s·Pa/kg x 10^9]**
Plywood EU	9	424	1.71	1.95	1.89
Plywood EU	12	434	3.02	4.12	3.82
Plywood EU 2	9	451	1.93	2.19	2.06
OSB	8	603	5.14	5.97	5.41
OSB EU	12	573	7.23	11.8	9.57
OSB EU 2	12	590	6.20	13.1	8.34
OSB EU	15	586	17.1	25.8	20.7
Plywood CAN	12	395	2.93	4.08	3.44
OSB CAN	11	579	6.53	8.68	7.29

TABLE A9. Water vapour resistance factor (from cup method) at 22 ℃, RH(1) = 58 %, RH(2) = 80 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m³]**	**MIN μ [-]**	**MAX μ [-]**	**MEAN μ [-]**
Plywood EU	9	424	38.20	43.60	42.11
Plywood EU	12	434	49.52	67.45	62.62
Plywood EU 2	9	451	45.13	51.22	48.24
OSB	8	603	123.10	142.74	130.01
OSB EU	12	573	114.48	185.38	152.00
OSB EU 2	12	590	97.31	204.45	130.68
OSB EU	15	586	222.22	334.92	269.57
Plywood CAN	12	395	45.78	63.17	53.68
OSB CAN	11	579	109.56	152.37	124.58

TABLE A10. Water vapour diffusion equivalent air layer thickness (from cup method) at 22 ℃, RH(1)= 58 %, RH(2) = 80 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m³]**	**MIN S_d [mm]**	**MAX S_d [mm]**	**MEAN S_d [mm]**
Plywood EU	9	424	336	384	371
Plywood EU	12	434	594	809	751
Plywood EU 2	9	451	379	430	405
OSB	8	603	1009	1170	1066
OSB EU	12	573	1408	2299	1870
OSB EU 2	12	590	1207	2556	1620
OSB EU	15	586	3333	5024	4044
Plywood CAN	12	395	577	802	676
OSB CAN	11	579	1271	1691	1420

TABLE A11. Water vapour permeance (from cup method) at 22 °C, RH(1) = 58 %, RH(2) = 80 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m³]**	**MIN 1/Z [Perm]**	**MAX 1/Z [Perm]**	**MEAN 1/Z [Perm]**
Plywood EU	9	424	8.96	10.22	9.29
Plywood EU	12	434	4.25	5.79	4.64
Plywood EU 2	9	451	7.98	9.07	8.52
OSB	8	603	2.94	3.40	3.24
OSB EU	12	573	1.49	2.35	1.87
OSB EU 2	12	590	1.33	2.82	2.26
OSB EU	15	586	0.68	1.02	0.88
Plywood CAN	12	395	4.29	5.97	5.15
OSB CAN	11	579	2.01	2.68	2.43

TABLE A12. Water vapour permeability (from cup method) at 22 °C, RH(1) = 58 %, RH(2) = 80 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m³]**	**MIN [Perm-inch]**	**MAX [Perm-inch]**	**MEAN [Perm-inch]**
Plywood EU	9	424	3.08	3.52	3.20
Plywood EU	12	434	1.99	2.72	2.18
Plywood EU 2	9	451	2.62	2.98	2.79
OSB	8	603	0.94	1.09	1.03
OSB EU	12	573	0.72	1.16	0.90
OSB EU 2	12	590	0.65	1.37	1.10
OSB EU	15	586	0.40	0.60	0.51
Plywood CAN	12	395	2.13	2.94	2.53
OSB CAN	11	579	0.88	1.22	1.09

TABLE A13. Water vapour permeability (from cup method) at 22 °C, RH(1) = 48 %, RH(2) = 94 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m³]**	**MIN δ [kg/m·s·Pa x 10⁻¹²]**	**MAX δ [kg/m·s·Pa x 10⁻¹²]**	**MEAN δ [kg/m·s·Pa x 10⁻¹²]**
Plywood EU	9	424	3.08	3.30	3.18
Plywood EU	12	434	2.84	3.18	3.03
Plywood EU 2	9	451	3.23	3.98	3.46
OSB	8	603	1.44	2.08	1.71
OSB EU	12	573	1.14	2.11	1.77
OSB EU 2	12	590	1.17	1.77	1.48
OSB EU	15	586	0.67	1.13	0.98
Plywood CAN	12	395	3.09	3.79	3.58
OSB CAN	11	579	1.15	2.30	1.61

TABLE A14. Water vapour resistance (from cup method) at 22 °C, RH(1) = 48 %, RH(2) = 94 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m³]**	**MIN Z [m²·s·Pa/kg x 10⁹]**	**MAX Z [m²·s·Pa/kg x 10⁹]**	**MEAN Z [m²·s·Pa/kg x 10⁹]**
Plywood EU	9	424	2.73	2.92	2.83
Plywood EU	12	434	3.87	4.33	4.06
Plywood EU 2	9	451	2.13	2.63	2.47
OSB	8	603	3.99	5.76	4.96
OSB EU	12	573	5.87	10.92	7.36
OSB EU 2	12	590	6.82	10.30	8.34
OSB EU	15	586	13.7	23.3	16.4
Plywood CAN	12	395	3.51	4.30	3.74
OSB CAN	11	579	4.96	9.87	7.70

TABLE A15. Water vapour resistance factor (from cup method) at 22 °C, RH(1) = 48 %, RH(2) = 94 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN μ [-]**	**MAX μ [-]**	**MEAN μ [-]**
Plywood EU	9	424	59.38	63.53	61.7
Plywood EU	12	434	61.62	69.02	64.74
Plywood EU 2	9	451	49.22	60.72	56.93
OSB	8	603	94.12	136.01	117.05
OSB EU	12	573	92.74	172.52	116.35
OSB EU 2	12	590	110.29	167.06	134.95
OSB EU	15	586	173.27	294.06	207.96
Plywood CAN	12	395	51.78	55.98	55.20
OSB CAN	11	579	85.30	169.66	132.39

TABLE A16. Water vapour diffusion equivalent air layer thickness (from cup method) at 22 °C, RH(1) = 48 %, RH(2) = 94 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN S_d [mm]**	**MAX S_d [mm]**	**MEAN S_d [mm]**
Plywood EU	9	424	534	572	555
Plywood EU	12	434	758	849	796
Plywood EU 2	9	451	418	516	484
OSB	8	603	781	1129	972
OSB EU	12	573	1150	2139	1443
OSB EU 2	12	590	1335	2021	1633
OSB EU	15	586	2686	4558	3223
Plywood CAN	12	395	689	845	734

TABLE A17. Water vapour permeance (from cup method) at 22 °C, RH(1) = 48 %, RH(2) = 94 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN 1/Z [Perm]**	**MAX 1/Z [Perm]**	**MEAN 1/Z [Perm]**
Plywood EU	9	424	6.00	6.41	6.17
Plywood EU	12	434	4.04	4.53	4.30
Plywood EU 2	9	451	6.64	8.18	**7.11**
OSB	8	603	3.04	4.39	3.58
OSB EU	12	573	1.61	2.97	2.50
OSB EU 2	12	590	1.70	2.57	2.13
OSB EU	15	586	0.75	1.28	1.10
Plywood CAN	12	395	4.05	4.98	4.70
OSB CAN	11	579	1.77	3.51	2.46

TABLE A18. Water vapour permeability (from cup method) at 22 °C, RH(1) = 48 %, RH(2) = 94 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN [Perm-inch]**	**MAX [Perm-inch]**	**MEAN [Perm-inch]**
Plywood EU	9	424	2.11	2.26	2.18
Plywood EU	12	434	1.95	2.18	2.08
Plywood EU 2	9	451	2.21	2.73	2.37
OSB	8	603	0.99	1.42	1.17
OSB EU	12	573	0.78	1.45	1.21
OSB EU 2	12	590	0.80	1.21	1.01
OSB EU	15	586	0.46	0.77	0.67
Plywood CAN	12	395	2.12	2.60	2.45
OSB CAN	11	579	0.79	1.58	1.10

TABLE A19. Water vapour permeability (from cup method) at 22 °C, RH(1) = 72 %, RH(2) = 97 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN δ [kg/m·s·Pa x 10^{-12}]**	**MAX δ [kg/m·s·Pa x 10^{-12}]**	**MEAN δ [kg/m·s·Pa x 10^{-12}]**
Plywood EU	9	424	7.40	8.06	7.66
Plywood EU	12	434	8.09	8.38	8.21
Plywood EU 2	9	451	7.51	9.14	7.94
OSB	8	603	4.00	5.18	4.59
OSB EU	12	573	6.04	6.57	6.33
OSB EU 2	12	590	5.00	5.87	5.49
OSB EU	15	586	3.09	4.17	3.62
Plywood CAN	12	395	8.21	9.29	8.78
OSB CAN	11	579	4.48	5.30	5.05

TABLE A20. Water vapour resistance (from cup method) at 22 °C, RH(1) = 72 %, RH(2) = 97 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN Z [m^2·s·Pa/kg x 10^9]**	**MAX Z [m^2·s·Pa/kg x 10^9]**	**MEAN Z [m^2·s·Pa/kg x 10^9]**
Plywood EU	9	424	1.12	1.22	1.18
Plywood EU	12	434	1.47	1.52	1.50
Plywood EU 2	9	451	0.93	1.13	1.08
OSB	8	603	1.60	2.07	1.82
OSB EU	12	573	1.18	2.05	1.96
OSB EU 2	12	590	2.04	2.40	2.19
OSB EU	15	586	3.71	5.01	4.34
Plywood CAN	12	395	1.43	1.54	1.52
OSB CAN	11	579	2.15	2.54	2.27

TABLE A21. Water vapour resistance factor (from cup method) at 22 °C, RH(1) = 72 %, RH(2) = 97 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m³]**	**MIN μ [-]**	**MAX μ [-]**	**MEAN μ [-]**
Plywood EU	9	424	24.23	26.42	25.55
Plywood EU	12	434	23.33	24.17	23.81
Plywood EU 2	9	451	21.38	26.03	24.76
OSB	8	603	37.94	49.11	43.17
OSB EU	12	573	28.51	32.31	30.93
OSB EU 2	12	590	33.30	39.11	35.74
OSB EU	15	586	46.90	63.28	54.75
Plywood CAN	12	395	21.03	23.81	22.31
OSB CAN	11	579	37.03	43.80	39.07

TABLE A22. Water vapour diffusion equivalent air layer thickness (from cup method) at 22 °C, RH(1) = 72 %, RH(2) = 97 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m³]**	**MIN S_d [mm]**	**MAX S_d [mm]**	**MEAN S_d [mm]**
Plywood EU	9	424	218	238	230
Plywood EU	12	434	287	297	293
Plywood EU 2	9	451	182	221	210
OSB	8	603	315	408	358
OSB EU	12	573	354	401	384
OSB EU 2	12	590	403	473	432
OSB EU	15	586	727	981	849
Plywood CAN	12	395	280	317	297
OSB CAN	11	579	422	499	445

TABLE A23. Water vapour permeance (from cup method) at 22 °C, RH(1) = 72 %, RH(2) = 97 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN 1/Z [Perm]**	**MAX 1/Z [Perm]**	**MEAN 1/Z [Perm]**
Plywood EU	9	424	14.4	15.7	14.9
Plywood EU	12	434	11.5	11.9	11.7
Plywood EU 2	9	451	15.4	18.8	16.3
OSB	8	603	8.4	10.9	9.7
OSB EU	12	573	8.5	9.6	8.9
OSB EU 2	12	590	7.3	8.5	8.0
OSB EU	15	586	3.5	4.7	4.1
Plywood CAN	12	395	10.8	12.2	11.5
OSB CAN	11	579	6.9	8.1	7.7

TABLE A24. Water vapour permeability (from cup method) at 22 °C, RH(1) = 72 %, RH(2) = 97 %.

Product	**Thickness d [mm]**	**Dry density ρ [kg/m^3]**	**MIN [Perm-inch]**	**MAX [Perm-inch]**	**MEAN [Perm-inch]**
Plywood EU	9	424	5.07	5.52	5.25
Plywood EU	12	434	5.54	5.74	5.63
Plywood EU 2	9	451	5.15	6.26	5.44
OSB	8	603	2.74	3.55	3.15
OSB EU	12	573	4.14	4.69	4.34
OSB EU 2	12	590	3.43	4.02	3.76
OSB EU	15	586	2.12	2.86	2.48
Plywood CAN	12	395	5.63	6.37	6.02
OSB CAN	11	579	3.07	3.63	3.46

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